Road-making

A TREATISE

ON

HIGHWAY CONSTRUCTION.

DESIGNED AS

A TEXT-BOOK AND WORK OF REFERENCE

FOR ALL WHO MAY BE ENGAGED IN THE

LOCATION, CONSTRUCTION, OR MAINTENANCE

OF

ROADS, STREETS, AND PAVEMENTS.

BY

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PREFACE.

ALTHOUGH volumes have been written on the subject of highway construction, still the matter is widely scattered through the pages of the standard works on engineering, technical journals and periodicals, in pamphlets and reports of city engineers, and is therefore not always easily accessible when wanted.

The author, having found the need of a comprehensive and practical work of reference upon the many subjects connected with highways, has in the following pages endeavored to collate the varied mass of information. In doing so he has derived valuable assistance from the works of the authors mentioned below (which works may be profitably studied by those desiring further information upon the subjects treated of), and takes this method of acknowledging his indebtedness and thanks, instead of inclosing every extract in quotation-marks.

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INTRODUCTION.

HISTORICAL SKETCH.

ROADS are pathways formed through a country to facilitate the movement of persons and exchange of commodities. They are of various kinds, according to the state of civilization and wealth of the country traversed; thus, they range from rude paths, passable only by pedestrians, to the comparatively perfect modern road, passable alike by persons and vehicles.

The motive for the formation of roads is found (1) in the inquisitive spirit of man, and his desire for intercourse with his fellows; (2) in the necessity of obtaining provisions for his sustenance in times of scarcity; and (3) in the desire to gratify his fancies with the products of other localities.

With the progress of civilization and the congregation of men in cities and towns their wants multiply, and the products of the earth have to be collected and transported to supply them. This collecting, transporting, and exchanging of products is trade or commerce, and its importance and expansion are directly proportional to the facilities afforded.

Countries inhabited by the least civilized people whose wants are supplied by nature in the immediate vicinity of their dwellings are almost destitute of roads; hence it has come to be said that roads are the physical symbol by which to measure the progress of any age or people. "If the community is stagnant, the condition of the roads will indicate the fact; if they have no roads, they are savages."

Although roads are the offspring of civilization, they have be-

come the chief factors, if not indeed the means, for its advancement. Without them the invention of printing and other arts so beneficial to the welfare of men would separately be ineffectual, or productive of advantages of a very limited extent. Without roads, the interchange of advantages, moral, intellectual, and physical, which now takes place in all highly civilized countries between the rural and urban population, could not be maintained; without them, indeed, large towns or cities could not continue to exist. The supply of the population collected in such places, with the various products of agriculture necessary to their physical existence, could not be sustained. Nor, on the other hand, would the rural population affording that supply be benefited by a return in exchange of the refinements of the town, and the various articles of luxury and necessity obtained by commerce from every part of the globe.

It is frequently asserted that, since the introduction and development of railroads, the latter have assumed to a greater and greater degree the functions of the common road, and that highways are no longer an indication of progress. This is true to only a limited extent. Railroads have changed the character of the traffic on the common roads, and personal travel for business or pleasure is no longer dependent upon the condition of the highways; but commercial intercourse as represented in the exchange of products is as much dependent upon the condition of the public road to-day as it ever was, for the reason that it is impossible to construct a railroad to the door of each producer and consumer. Hence railroads never can supersede the common road, and every ton of freight carried by them must be conveyed over a highway at either or both terminals, and the cost of this highway transportation has a marked influence not alone upon the price paid by the consumer, but also on the profit realized by the producer.

If railroads may be compared to the arteries of a living body, then the common roads are the veins, and each is equally necessary in quickening and communicating life to the parts to which they lead. But the true relation between railroads and wagon-roads frequently seems to be lost sight of; the functions of each are quite different and in no sense rivals. The highway serves the very important purpose of effecting local intercourse and of connecting the local freight and passenger traffic with the railroad service. Roads running parallel to the railroad and connecting towns al-

ready joined by the railroad are of but little importance. It is the roads running at an angle with the railroad and connecting it with the country to the right and left, thus acting as feeders, that require attention in modern times. In Baden, Germany, this relation of the roads to the railroads was early recognized by striking from the list of state roads all those that ran parallel to the railroad or had lost their importance by its construction, in order to save funds for the support of the others; while most of those running across the railroad, if they crossed at a station so that they served as feeders, were raised to the grade of state roads.

The importance of roads to the welfare of nations was not unknown to the ancients. The senate of Athens, the governments of Lacedæmon, Thebes and other states of Greece bestowed much care upon them. The Carthaginians were systematic and scientific road-makers; they built up and consolidated an empire so prominent in military and naval achievements and in the arts and industries of civilized life that for four hundred years it was able to hold its own against the preponderance of Greece and Rome.

In Peru the Incas built great roads, the remains of which attest their magnificence. Humboldt in his "Aspects of Nature" speaks of the mountain road from Quito to Cuzco as "a marvellous work, not inferior to the most imposing Roman roadways." It was from 1500 to 2000 miles in length, and most of it was at an elevation of over 12,000 feet above the level of the sea; it was 20 feet wide and paved with stones 10 feet square, and had a running stream and a row of shade-trees on each side. Prescott in his "History of Peru," in speaking of this road, says that "it was conducted over sierras covered with snow; galleries were cut through the living rock; rivers were crossed by means of bridges swung suspended in the air; precipices were scaled by stairways hewn out of the native bed, and ravines of hideous depth were filled up with solid masonry."

As to when paved roads were first introduced little is known, but Strabo informs us that the city of Babylon was paved at a very early date. The date assigned (2000 B.C.) is perhaps fabulous, though it was quite within the capacity of the builders of the city walls, palaces, and bridges across the Euphrates to pave the city in good style.

The highway leading from Babylon to Memphis was paved at an early date, and along it arose the cities of Nineveh, Palmyra, Damascus, Tyre, Antioch, and other great commercial cities.

The Romans learned the art of making paved roads from the Carthaginians, and the highways constructed by them are great monuments in this department of art.

The first Roman road was constructed under the direction of the censor Appius Claudius (312 B.C.). This road, named after him the Appian Way, was frequently, on account of its excellence, called the "queen of roads." Under Augustus and Julius Cæsar the Roman capital was made to communicate with all the chief towns by paved roadways, and during the last African war a road of this kind was constructed from Spain through Gaul to the Alps. Later these great lines of communication were extended through Savoy, Dauphiné, and Provence; through Germany, every part of Spain, through Gaul, and even to Constantinople; through Hungary, Macedonia, and to the mouths of the Danube. Neither did the interposition of seas obstruct the labor or daunt the enterprise of this great people. The lines of communication thus constructed to the shores of the continent of Europe were continued at corresponding points of the neighboring islands and continents. Sicily, Corsica, Sardinia, England, Africa, and Asia were accordingly penetrated and intersected by roads, forming the continuation of the great European lines. These gigantic works were the most solid structures of their kind which have been formed in any age, and many of them still remain, often forming the foundation of modern roads and in some instances constituting the road-surface now used. From these remains and the accounts of ancient writers we are enabled to follow the methods employed in their construction. The engineering appears to have been very simple. A prominent landmark was selected in the direction desired, and the road located on an absolute straight line without reference to intervening obstacles. The roads were divided into military and local ways. The first were built to facilitate the movement of troops and to connect the capital with the principal cities and strategic points. They were constructed and kept in repair by the imperial government. The second were the routes of commerce and connected towns and trade centres, and were constructed to facilitate the relations and intercourse of traffic; they were built and maintained by the municipal

governments. The width of the roads varied from 8 to 20 feet, and the method of construction was as follows: A trench was excavated the entire length and width of the roadway; in this trench the road materials were placed, arranged in four layers having a total thickness of about 3 feet: (1) the *statumen*, consisting of two courses of large flat stones laid in lime-mortar; (2) the *rudus*, composed of broken stones mixed with one third their quantity of lime and well consolidated by ramming; (3) the *nucleus*, a mixture of broken brick, potsherds, tiles, gravel, and lime; (4) the *summa crusta*, a pavement of irregularly-shaped stones about six inches thick, closely jointed and fitted with the utmost nicety. These roads bore uninjured the weight of columns, obelisks, and other immense blocks of stone weighing hundreds of tons; notwithstanding this the utmost weight which each class of vehicle was permitted to carry was regulated by law, and those laws were strictly enforced. Although these roads were eminently durable, they were deficient in the other qualities requisite for a good road, and Horace states that they were "less fatiguing to people who travel slowly."

In the breaking-up of society which followed the decline of the Roman Empire, the roads fell out of repair and finally into ruin. During the Dark Ages they were regarded with terror as aids to plunder, and such intercouse as was maintained took place almost exclusively by rude paths capable of being passed on foot, or at best by horses. With the reconstruction of society in Europe the roads gradually became practicable for pack-animals and the rude vehicles of the time; but no serious attempt was made to restore or replace the public highways until the middle of the eighteenth century. About this time the revival of road construction was almost simultaneous in England and France, and shortly afterwards the other chief countries of Europe took up the matter.

Regarding the condition of the English highways a hundred and fifty years ago, Lord Macaulay tells us that it was no uncommon thing for the fruits of the earth to rot in one place when a score of miles away the people were suffering from a scarcity of the very food which was spoiling and almost within their reach. The roads were so wretched that the food could not be transported. At this time each parish was obliged to build and maintain the roads within its confines, and it not infrequently happened that a poor

and impoverished agricultural community was expected to maintain a highway between two rich and prosperous towns.

Mr. Arthur Young in his "Six Months' Tour in the North of England" gives us the following account of the state of the roads at that time (1770): "I know not in the whole range of language terms sufficiently expressive to describe this infernal road. Let me most seriously caution all travellers who may accidentally propose to travel this terrible country to avoid it as they would the devil; for a thousand to one they break their necks or their limbs, by overthrows or breaking-downs. They will here meet with ruts, which I measured, actually four feet deep, and floating with mud only from a wet summer. What, therefore, must it be after a winter? The only mending it receives is tumbling in some loose stones, which serve no other purpose than jolting a carriage in the most intolerable manner. These are not merely opinions, but facts; for I actually passed three carts broken down in these eighteen miles of execrable memory."

England sought to improve the ill-condition of her highways by the establishment of a comprehensive system of turnpikes, and before the beginning of this century thirty thousand miles of these roads had been built; but they were constructed in such an imperfect manner that they were but little improvement on the old roads. Even as late as 1809 the roads answered the description of Mr. Young, and little improvement was effected till the advent of MacAdam and Telford. Contemporaries and in some respects advocates of rival systems, to these two men England owes her present admirable system of roads; and Charles Dickens wrote: "Our shops, our horses' legs, our boots, our hearts, have all been benefited by the introduction of MacAdam."

The French and the Swiss probably have the best highways of any of the European countries. Until the time of Louis XIV. the roads of France received no more attention than did those of England. This monarch had several fine roads made in the environs of Paris for his personal use and pleasure. They were very wide and paved only in the centre. Shortly after the construction of these royal roads the nation began to appreciate the advantage of good roads,but it was not until the advent of the first Napoleon that the modern system of magnificent highways was inaugurated, solely for military purposes, and this object has never been lost sight of; so

that, although in modern times their use as a means of communication for the people accounts for their great and increasing number, it is largely owing to their military character that the French government expends the enormous sums it does annually on the national roads.

The material and financial prosperity, thriftiness, and contentment of the French people has long excited the admiration of the world; neither internal revolution nor defeat from abroad appears to have entailed upon them burdens too heavy for them to bear. Students of economic problems ascribe this marvellous condition to the far-reaching and splendidly maintained system of highways, on which the obstacles to economical transportation have been reduced to the minimum.

In the United States the highways have not improved as rapidly as other institutions; in fact, they are very inferior to those of Europe. The reason for this may be attributed to several causes, among which may be mentioned (1) the excellence of the railroad systems and waterways; (2) the indifference of those in charge of highway maintenance; (3) the want of appreciation of the benefits of good roads and the fear of increased taxation on the part of the rural population; (4) the dispersion of the people over large areas in their search for desirable localities for residence; and (5) the ill-effects of the system requiring the personal service of the rural population on the highways.

The experience of Europe in road improvement shows that the highways should be taken as much as possible out of the hands of local authorities, and administered by either national or state governments in accordance with the needs of the people who use the roads; and that as the whole public is benefited by good roads, therefore all should pay for their improvement and maintenance. This view of the subject is not new in the United States, for Washington recommended in a letter to Patrick Henry that the roads of Virginia be taken away from the control of the county courts and be given to the State authorities. One of Hamilton's pet schemes was that of road improvement, and he recognized thoroughly that roads left to local authority would never be satisfactorily built. During the past ninety years there has been more or less national legislation in regard to common roads. Several very comprehensive measures have passed one or another of the Houses

of the National Congress, but the only road of any consequence constructed by the government was the national road (650⅝ miles in length, 80 feet in width, and macadamized for a width of 30 feet), which it originally was intended should go from the tide-water of the Atlantic Ocean to the Ohio River. It was built from Cumberland in Maryland to a point in Ohio several hundred miles from the Ohio River, and there it was allowed to stop, being finally donated to the States through which it passes. In this way ended the first great effort of the Federal Government to build and establish, as the Constitution of the United States contemplated, a system of post-roads all over the country.

The date of the first introduction of street pavements cannot be determined with certainty. Livy informs us that in the year 584 (about 170 B.C.) the censors caused the streets of Rome to be paved from the ox market to the temple of Venus. Streets paved with lava, having deep ruts worn by the wheels of chariots, and raised banks on each side for foot-passengers, are found at Pompeii and Herculaneum.

Abderahman, the caliph of Cordova, Spain, caused the streets of that city to be solidly paved, A.H. 236 (A.D. 950), and a man might walk after sunset ten miles in a straight line by the light of the public lamps.

The date of the first introduction of pavements into London is unknown, but the streets of that city were not paved at the end of the eleventh century. It is related that in the year 1190 the church of St. Mary-le-Bow in Cheapside was unroofed by a violent wind, and that four pillars, 26 feet in length, sunk so deep into the ground that scarcely 4 feet of them appeared above the surface of the soft earth forming the street. Holborn was first paved in 1417, and Smithfield in 1614. The first act for paving and improving the City of London was passed in 1532. The streets were described in the simply-worded statute as "very foul, and full of pits and sloughs, so as to be mighty perilous and noyous, as well for all the king's subjects on horseback as on foot with carriages" (litters).

The capital of France was not paved in the twelfth century, for Rigord, the physician and historian of Philip II., relates that, the king standing one day at a window of his palace near the Seine and observing that the carriages which passed threw up the dirt

in such a manner that it produced a most offensive stench, his majesty resolved to remedy this intolerable nuisance by causing the streets to be paved, which was accordingly done. The orders for this purpose were issued by the government in the year 1184, and upon that occasion, it is said, the name of the city, which was then called Lutetia, on account of its dirtiness, was changed to that of Paris.

Dijon, France, had paved streets as early as 1391, and it is remarked by historians that after this was done dangerous diseases, such as dysentery, spotted fever, and others, became less frequent in that city.

In the United States, Boston, Mass., appears to have been the first city to pave its streets, for when Josselyn visited that city in 1663 he found many streets paved with pebbles; and Ward said in 1699: "The buildings, like their women, being neat and handsome, and their streets, like the hearts of the male inhabitants, are paved with pebble." Drake says that the paving of the public streets began very early and was made of importance after 1700; the sidewalks were also early paved with cobblestones and flags.

We learn that the first regular paving of a Philadelphia street was due to an accident. A man on horseback being mired and thrown from his horse, breaking his leg, a subscription was raised and the street paved with pebbles from the river-bank. In 1719 many sidewalks were being paved with brick and the cartway with cobblestone.

In 1750 the grand jury represented the great need of paved streets, "so as to remedy the extreme dirtiness and miry state of the streets;" but the first general effort worthy of mention to pave the streets was made in 1761–62, and then the only means applied to the purpose was that produced by lotteries.

Authority to construct toll-roads was first granted in England, in 1346, but their construction did not become general until 1676, and they were entirely abolished in 1878.

In the United States the first toll-road company was incorporated in Pennsylania in 1792, to construct and maintain an artificial road from Philadelphia to Lancaster, a distance of about 70 miles. The framers of the act authorizing the construction of this road recognized the importance of the relation between the load and the width of the wheel-tire. The rate of toll was graded

according to the width of the tire, and the maximum load to be carried by the different widths of tire was distinctly stated. Vehicles with tires of less breadth than four inches were not allowed to carry more than two and a half tons between the first day of December and the first day of May, and not more than three tons during the rest of the year.

The act also provided for the placing of milestones and the erection of guide-posts at all intersecting roads, with the name of the place to which they led and its approximate distance in miles.

Though considerable advance in processes and machines have been made during the past hundred years, the two chief factors in the preservation of roads so ably regulated in the above mentioned act are still the same, and in many cases are the cause of the evils we suffer from in the shape of bad highways.

A TREATISE ON HIGHWAY CONSTRUCTION.

CHAPTER I.

PAVEMENTS.

1. General Considerations.—The object of a pavement is (1) to secure a water-tight covering that will preserve the natural soil from the effects of moisture, and not, as commonly supposed, to support the vehicles, the weight of which and that of the covering material must be actually borne by the natural soil. (2) To furnish a smooth surface on which the force of traction will be reduced to the least possible amount, and over which vehicles may pass with safety and expedition at all seasons of the year.

2. The Qualities essential to a good pavement may be stated as follows:

(1) It should be impervious.

(2) It should afford good foothold for horses.

(3) It should be hard and durable, so as to resist wear and disintegration.

(4) It should be adapted to every grade.

(5) It should suit every class of traffic.

(6) It should offer the minimum resistance to traction.

(7) It should be noiseless.

(8) It should yield neither dust nor mud.

(9) It should be easily cleaned.

(10) It should be cheap.

3. Interests affected in the Selection.—Of the above requirements, numbers 2, 4, 5, and 6 affect the traffic and determine the cost of haulage by the limitations of loads, speed, wear and tear of horses and vehicles. If the surface is rough or the foothold bad, the weight of the load a horse can draw is decreased, thus necessitating the making of more trips or the employment of more horses and vehicles to move a given weight. A defective surface necessitates a reduction in the speed of movement and consequent loss of time; it increases the wear of horses, thus decreasing their life-service, and lessens the value of their current services; it also increases the cost of maintaining vehicles and harness.

Numbers 7, 8, and 9 affect the occupiers of the adjacent premises, who suffer from the effect of dust and noise; and second, the owners of said premises, whose income from rents is diminished where these disadvantages exist.

Numbers 3 and 10 affect the taxpayers alone, first as to the length of time during which the covering remains serviceable, and second as to the amount of the annual repairs. Number 1 affects the adjacent occupiers principally on hygienic grounds. Numbers 7 and 8 affect both traffic and occupiers.

4. Selection of Pavements.—In the selecting of the most suitable pavement, whether for a street or a country road, all classes of citizens are alike interested; for of all the systems of intercommunication none is brought into more direct contact with the people than the public highway, and its effect upon the price of commodities is felt by all. Not a ton of agricultural or mechanical produce can reach its destination without first and last paying toll to the condition of the highway over which it has to be hauled; in the form of time, wear and tear of horses, harness, and vehicles thus enhancing its cost to the consumer without any increased benefit to the producer, who must be compensated for the cost of all unnecessary expenses of transportation due to the ill condition of the highway.

5. Cost of Wagon Transportation.—It is apparent that but few people comprehend the cost of transportation by horses and wagons, or realize the amount of money annually wasted by the ill condition of the roadways.

Table I shows from actual observation the cost of moving a load of one ton a distance of one mile on level roadways with

different pavements in the usual condition in which they are maintained. The excessive amount of these charges is seen when it is remembered that the same goods using the roadways are now carried by the railroads at an average cost of $\frac{6}{10}$ of a cent per ton-mile.

TABLE I.

COST OF TRANSPORTATION BY HORSES AND WAGONS PER TON-MILE ON DIFFERENT ROAD-COVERINGS.

Iron rails	1.28	cents per ton-mile
Asphalt	2.70	" "
Stone, paving, dry and in good order	5.33	" "
" " ordinary condition	12.00	" "
" " covered with mud	21.30	" "
Broken stone, dry and in good order	8.00	" "
" " moist " " "	10.30	" "
" " ordinary condition	11.90	" "
" " covered with mud	14.30	" "
" " ruts and mud	26.00	" "
Earth, dry and hard	18.00	" "
" ruts and mud	39.00	" "
Gravel, loose	51.60	" "
" compacted	12.80	" "
Plank, good condition	8.80	" "
Sand, wet	32.60	" "
" dry	64.00	" "

6. In 1890 the railroads of the United States carried over 600,000,000 tons of freight. Most if not all of this had to be handled at one or both terminals in wagons. If the distance hauled was but one mile and the rate per ton-mile $22\frac{1}{4}$ cents, which is the average rate of haulage, the cost would be $133,500,000. The low rate of railroad transportation has been achieved by careful and scientific study, and by daily attention to every portion of the road-bed and rolling stock. Defective parts are instantly removed and new ones substituted so that the road is always in good order. But pavements once laid are left to batter the vehicles, and the vehicles, in return, to pound the pavements: little or no attention being paid to them until they finally become unendurable and are entirely renewed. Moreover, on every well-managed railroad the statistics of cost of transportation are the subject of the most scientific study, and at the end of each year it is exactly ascertained

just how much it has cost to haul a ton of freight one mile, and what proportion of this is for train service, what for maintenance of rolling stock, what for maintenance of way, and so on; whereas very few engineers in charge of highways have attempted to find out accurately what is the relative damage done to vehicles and horses by different kinds of pavements, what is the relative amount of force required to draw a unit of weight on different surfaces, what is the relative cost of maintaining different pavements during a term of years under a unit of traffic, or what is the exact proportion of horses falling on different surfaces.

7. Effect of Reducing the Cost of Wagon Transportion.—If the cost of wagon transportation could be reduced by the improvement of the highways to, say, five cents per ton-mile, what would be the result? It would create an annual saving of many millions of dollars and it would put in motion a large tonnage of various kinds of merchandise that cannot now be handled with profit; it would give a large margin of profit on many products which are now moved with little profit, and would directly benefit both the producer and the consumer.

The cost of wagon transportation over the roads of France does not exceed one third the like expense in America, it being common in rural districts to haul three tons and in the cities from three to five tons net freight with one horse.

8. Problem involved in the Selection of Pavements.—The problem involved in the selection of the most suitable pavement is composed of the following factors: first, adaptability; second, desirability; third, serviceability; fourth, durability; fifth, cost.

9. Adaptability.—The best pavement for any given roadway will depend altogether on local circumstances. Pavements must be adapted to the class of traffic that will use them. The pavement suitable for a road through an agricultural district will not be suitable for the streets of a manufacturing centre, nor will the covering suitable for heavy traffic be suitable for a pleasure-drive or a residential district.

General experience indicates the relative fitness of the several materials as follows:

For country roads, suburban streets, and pleasure-drives, broken stone. For streets having heavy and constant traffic, rectangular blocks of stone laid on a concrete foundation with the joints filled

with bituminous or Portland cement grout. For streets devoted to retail trade and where comparative noiselessness is essential, asphalt, wood, or brick.

10. Desirability.—The desirability of a pavement is its possession of qualities which make it satisfactory to the people using and seeing it. Between two pavements alike in cost and durability, people will have preferences arising from the condition of their health, personal prejudices, and various other intangible influences, causing them to select one rather than the other in their respective streets. Such selections are often made against the demonstrated economies of the case, and usually in ignorance of them. Whenever one kind of pavement is more economical and satisfactory to use than is any other, there should not be any difference of opinion about securing it, either as a new pavement or in the replacement of an old one.

Popular prejudices about pavements affect the prices of real estate upon paved streets, and so help to determine their desirability. A stranger's impression of a city or town depends largely upon the ease with which he can go from place to place in the transaction of business or in the pursuit of pleasure, and he is pleased or displeased exactly in proportion to the smoothness of his journey or the ruggedness of his way. Massive business blocks, pretentious private residences, stately public buildings, beautiful parks and lawns, possess no attraction for one who is compelled to pick a way for his feet and keep his eyes on the ground for fear of stumbling over jagged stones or falling in the mud. To man and beast alike, the roadway that offers a few or no obstacles to easy travel is a delight which shortens the journey by mitigating the pangs of fatigue.

To persons who ride for pleasure or for health, rough pavements cause great annoyance. The pleasure of fast driving in the parkways or roadways devoted to that purpose is defeated by the necessity of jolting over rough pavements until the driveway is reached, and in the case of invalids the rough roadways prevent the taking of air altogether in many cases.

11. The economic desirability of pavements is governed by the ease of movement over them, and is measured by the number of horses or pounds of tractive force required to move a given weight, usually one ton, over them. The following table shows the relative

tractive force required upon level roads formed of different materials, asphalt being taken as the standard of excellence in this respect:

TABLE II.

NUMBER OF HORSES REQUIRED TO MOVE ONE TON ON DIFFERENT PAVEMENTS.

Asphalt	1.00
Stone blocks, dry and in good order	1.50 to 2.00
" " in fair order	2.00 " 2.50
" " covered with mud	2 00 " 2.70
Macadam, dry and in good order	2.50 " 3.00
" in a wet state	3.30
" in fair order	4.50
" covered with mud	5.50
" with the stones loose	5.00 " 8.20

See also Tables L and LI, pages 261 and 264.

12. From Table II it is seen that to move the same load at the same speed and for the same length of time, with the same fatigue to each horse, requires from 1½ to 3 horses on stone block pavements, and 2½ to 8½ on macadam, while for asphalt but 1 is required.

If iron rails be taken as the standard of excellence, the number of horses required will be as follows:

Iron rails	1
Asphalt	1¼
Stone block, best condition	3¼
" " ordinary condition	5
" " bad "	8
Macadam	5.7 to 8
Cobblestones, good	6.6 " 13.3
" ordinary	25
Earth, dry	20
Sand	40

13. Economy of Smoothness.—From the above table the great economy of smoothness becomes at once apparent. But it is evident that, as in all lines of transportation, the greatest resistance regulates the load over the rest of the route, unless there be auxiliary power; so the continuity of the surface should remain unbroken by any other grade of material which would increase the resistance.

The advantages of smooth pavements to owners and users of horses and vehicles are enormous. With them one third greater loads could be moved; there would be no stuck teams, fewer worried, beaten horses, fewer angry, overworked drivers, and thus fewer delays and interruptions to business.

14. Serviceability.—The serviceability of a pavement is its quality of fitness for use. This quality is measured by the expense caused to the traffic using it, viz., the wear and tear of horses and vehicles, loss of time, etc. No statistics are available from which to deduce the actual cost of wear and tear. It has been estimated as follows:

On cobblestones	5	cents per mile travelled
" belgian block	4	" "
" granite block	3	" "
" wood	2.5	" "
" broken stone in first-class condition	1.2	" "
" asphalt	1	" "

The serviceability of any pavement depends in a great measure upon the amount of foothold afforded by it to the horses, provided, however, that its surface be not so rough as to absorb too large a percentage of the tractive energy required to move a given load over it. Cobblestones afford excellent foothold, and for this reason are largely employed by horse-car companies for paving between the rails; but the resistance of their surface to motion requires the expenditure of about 280 pounds of tractive energy to move a load of 1 ton. Asphalt affords the least foothold, but the tractive force required to overcome the resistance it offers to motion is only about 30 pounds per ton.

15. Comparative Safety.—The comparison of pavements in this respect is the distance travelled before a horse falls. The materials affording the best foothold for horses are as follows, stated in the order of their merit:

(1) Earth dry and compact.
(2) Gravel.
(3) Broken stone (macadam).
(4) Wood.
(5) Sandstone and brick.
(6) Asphalt.
(7) Granite blocks.

16. The most complete observations made in the United States to ascertain the prevalence of accidents on the different pavements were made under the direction of Capt. F. V. Greene, the results of which show that a horse may travel before falling on

Asphalt (Trinidad)	583 miles
Granite	413 "
Wood	272 "

17. Observations for the same purpose were made in London under the direction of Col. Haywood. The results were as follows. The three classes of pavements, wood, asphalt, and stone, were observed as nearly as was possible under the same conditions of space, weather, gradients, and soundness. The result of fifty days' observation showed that before meeting with an accident a horse would travel a far greater distance on wood than he could either on asphalt or stone. The following table shows the distance travelled by a horse before meeting with an accident:

DRY-WEATHER DISTANCES.

Wood	646 miles
Asphalt	223 "
Granite	78 "

DAMP-WEATHER DISTANCE.

Wood	193 miles
Asphalt	125 "
Granite	168 "

THOROUGHLY-WET-WEATHER DISTANCES.

Wood	432 miles
Asphalt	192 "
Granite	537 "

Another mode of observation gave the distance travelled as follows:

Wood	446 miles
Asphalt	191 "
Granite	132 "

18. The foregoing figures appear to show that

(1) Asphalt was most slippery when merely damp, and safest when perfectly dry.

(2) That granite was most slippery when dry and safest when wet.

(3) That wood was most slippery when damp and safest when dry. It will be noticed that only under a single condition, and that the least persistent, is granite safer than wood or asphalt, and that wood is safer than asphalt under all circumstances.

Granite was least safe and wood and asphalt most safe when clean.

19. Slight rain makes asphalt and wood more slippery than they are at other times. On asphalt the slipperiness begins almost immediately the rain commences. Wood requires more rain before its worst condition ensues. The slipperiness lasts longer upon wood, on account of its absorbent nature, than it does upon the asphalt. When dry weather comes after the rain, then asphalt is in its most slippery condition and horses fall upon it very suddenly. On wood their efforts to save themselves are more effectual. Wood is also frequently in that peculiar condition of surface in which horses slip or slide along it without falling. A small quantity of dirt on asphalt makes it very slippery. In damp weather granite blocks become very greasy and slippery; in dry weather, if of a hard variety, the surface polishes and becomes rounded and the only foothold is by the joints between the blocks.

In winter, during frost, asphalt is usually dry and safe; wood, retaining moisture, is very slippery. Under snow there is very little if any difference between the safety of asphalt and wood.

20. The difference in the results obtained by Capt. Greene and Col. Haywood may be due in the case of the wood and stone pavements to climatic causes. London is more damp and foggy than any one of the American cities in which the traffic was observed, and therefore its pavements would be more slippery. The difference in the asphalt returns may be accounted for by the difference in the character of the material. The asphalt pavements in London are made from natural bituminous rock, which makes a very smooth, hard surface, while the American pavements are made from natural bitumen mixed with sand, which forms a rough, granular surface. Moreover, these observations were made some eighteen years ago, at a time when asphalt was a new thing and its proper treatment very insufficiently understood. It was not then recognized that asphalt requires to be constantly and thoroughly cleansed in order to do justice to itself. That the number of falls on asphalt is decreasing as its use is becoming more extended is shown by the following:

In Berlin in 1885, 4403 horses fell on an area of 398,000 square yards of asphalt pavement, in 1887 the number was reduced to 2456, while the area had increased to 485,000 square yards.

That asphalt is but slightly more dangerous than some kinds of stone is shown by observations made at Paris some years ago in two streets, one paved with the hard sandstone much used in that capital, and the other with asphalt. In the street paved with stone one out of every 1308 horses fell, and in that paved with asphalt one out of every 1409 fell.

21. Slipperiness can be cured on both wood and asphalt: on the asphalt by sprinkling it with sand, on the wood by sprinkling it with gravel. The result in both cases is dirt. The sand thrown on the asphalt tends to wear it out; the gravel thrown on the wood tends to preserve it.

22. Kinds of Falls and their Causes.—The commonest falls on wood are falls on the knees, which are less likely to injure the horses and are less inconvenient to the traffic than other falls. Falls on haunches are more numerous on asphalt than on wood. Of complete falls there are fewest on wood and most on granite. The falls on asphalt are generally due to sudden pulling up and sharp turning; those on granite, to the excessive width of the blocks, which fail to afford proper foothold.

23. Durability.—The durability of a pavement is its quality, which relates to the length of time during which it is serviceable and not to the length of time it has been down. The only measure of the durability of a pavement *is the amount of traffic tonnage it will bear before it becomes so worn that the cost of replacing it is less than the expense incurred by its use.*

24. As a pavement is a construction, it necessarily follows that there is a vast difference between the durability of the pavement and the durability of the materials of which it is made. Iron is eminently durable, but as a paving material it is a failure.

25. Durability and Dirt.—The durability of a paving material will vary considerably with the condition of cleanliness observed. One inch of overlying dirt will most effectually protect the pavement from abrasion and indefinitely prolong its life. But the dirt is expensive, it injures apparel and merchandise, and is the cause of sickness and discomfort. In the comparison of different pavements no traffic should be credited to the dirty one.

26. A pavement so rough and insecure that the traffic is kept off the road might be a most durable one, but it certainly would be lacking in serviceability. In a general way of speaking, the value of city property depends upon the volume of the traffic in the street upon which it is located. Ordinarily a pavement is not wanted by the owners of property on the street, however durable it may be, if it lacks serviceability; and they may not want it, even when it is serviceable, if it is not popular.

27. Life of Pavements.—The life or durability of the different pavements under like conditions of traffic and maintenance may be taken as follows:

Granite block	12 to 30 years
Sandstone	6 " 12 "
Asphalt	10 " 14 "
Wood	3 " 7 "
Limestone	1 " 3 "
Brick	5 " ? "
Macadam	?

28. Cost.—The question of cost is the one which usually interests the taxpayers, and is probably the greatest stumbling-block in the attainment of good roadways. The first cost is usually charged against the property abutting on the highway to be improved. The result is that the average property-owner is always anxious for a pavement that costs little, because he must pay for it, not caring for the fact that cheap pavements soon wear out and become a source of endless annoyance and expense. Thus false ideas of economy always have stood and undoubtedly to some extent always will stand in the way of realizing that the best is the cheapest.

29. The pavement which has cost the most is not always the best, nor is that which has cost the least the cheapest; *the one which is truly the cheapest is the one which makes the most profitable returns in proportion to the amount which has been expended upon it.* No doubt there is a limit of cost to go beyond which would produce no practical benefit, but it will always be found more economical to spend enough to secure the best results, and it will always cost less in the long-run. One dollar well spent is many times more effective than one half the amount injudiciously expended in the hopeless effort to reach sufficiently good results which may look as

well for the time, no matter how soon it may have to be done over again.

30. A good roadway should cost more to build than a poor one, but it is often the case that the poor road costs as much as a good one would. But even when a good one is more expensive, it will be easier and cheaper to keep in repair, and will last many years longer, while its advantages and the saving to those who daily use it will much more than compensate for the extra expense they may have been put to in building it.

31. Economy and Public Bodies.—The true economy for public bodies which never die is to secure the best, in the best possible manner; for the best, every essential point being considered, is the cheapest. If a cheap pavement is adopted, the cost to maintain it will be so excessive as to more than make the difference between its first cost and that of a first-class one. As an instance of the profitable results of this policy the experience of the city of Liverpool, England, may be cited.

After many years of experiment and the expenditure of vast sums of money in pavements, the corporation of Liverpool now points with justifiable pride to its 250 miles of the best paved streets in the world.

The policy adopted by this corporation in the execution of public works in the best possible manner, and generally by their own workmen, has proved successful in every way ; and, by a judicious primary expenditure, the cost of maintenance of the roads, sewers, and other public works is reduced to a minimum, and the greatest economy is thereby attained.

The laying of the impervious pavement which was adopted in 1872 for the carriage-ways of the city has been continued up to date without intermission, and is still in progress, resulting in nearly 1,750,000 yards, superficial, of impervious carriage-way pavements, and a saving by the execution of this class of work unprecedented in municipal experience.

The financial result can best be shown by the following: "Dealing with the year 1879, under the present city engineer (Mr. Clement Dunscombe, M.A., M. Inst. C. E.), the estimated expenditure for the general repairs to the roads in this city was £28,000 ($136,080), the mileage of adopted roads at that time being 226 miles. Concurrently with the extension of the impervious carriage-way

pavements, the expenditure under this head has been reduced year by year till the estimated cost for the current year (1889) is only £8400 ($40,824), with a street mileage under repair of 254 miles. This reduction has not been effected, as might at first sight be supposed, by an increased rate under this head, due to an augmented expenditure of capital requiring the provision of additional interest and sinking fund to redeem the original debt for paving and like works within 23 years (from 1870, when the loan was effected, to 1893, when it will be paid), as the amount raised on paving-rate account in the year 1879 was, approximately, £17,000 ($82,620) more than in the year 1889, although the interest and sinking fund on the debt had increased from about £13,000 ($63,180) per annum in the year 1879 to about £47,000 ($228,420) per annum in the year 1889."

Permission is never given to private companies or persons to cut through the pavement in any street for any purpose. When such work is necessary, the corporation will do it in its own thorough way, and the interested parties must pay the entire cost—a regulation worth noting.

With the introduction of the improved payments, it was found absolutely necessary, in order to attain the best results, to purchase the street-railroad tracks and reconstruct them in connection with the new pavements. Accordingly the city purchased some fifty miles of street-railroad tracks, and reconstructed them in a most substantial manner, and then rented them to the several original car companies at a fixed annual rental of 10 per cent on their cost. The city keeps the tracks in good condition. The success of these lines is conclusive proof that when street-car tracks are well designed and properly constructed they do not form the slightest impediment even to the narrowest-wheeled vehicles.

32. Economic Benefit.—The economic benefit of a good roadway is comprised in its cheaper maintenance, greater and easier facility for travelling, thus reducing the cost of transportation, less cost of repairs to vehicles, less wear of horses (thus increasing the life and time of serviceability and enhancing the value of their present service), saving of time, ease and comfort to those using it.

33. First Cost.—The cost of construction is largely controlled by the locality of the place, its proximity to the particular material used, and the character of the foundation. Tables XXVII, XXVIII,

XXIX, XXX, XXXV, XXXVI, XXXVII, XLI, XLII, and XLIII show the cost of different pavements in several of the principal cities of America.

34. The Relative Economies of Pavements—whether of the same kind in different condition or different kinds in like good condition—are sufficiently determined by summing their cost under the following headings of account:

(1) Annual interest upon first cost.
(2) Annual expense for maintenance.
(3) Annual cost for cleaning and sprinkling.
(4) Annual cost for service and use.
(5) Annual cost for consequential damages.

35. *First.*—The first cost of a pavement is like any other permanent investment, measurable for purposes of comparison by the amount of annual interest on the sum expended. Thus, assuming the worth of money to be 4%, a pavement costing \$4 per square yard entails an annual interest loss or tax of \$0.16 per square yard.

36. *Second.* **Maintenance.**—Under this head must be included all outlays for repairs and renewals which are made from the time when the pavement is new and at its best to a time subsequent when, by any treatment, it is again put in equally good condition. The gross sum so derived divided by the number of years which elapse between the two dates gives an average annual cost for maintenance.

37. Maintenance means the keeping of the pavement in a condition practically as good as when first laid. The cost will vary considerably, depending not only upon the material and manner in which it is constructed, but upon the condition of cleanliness observed, and the quantity and quality of the traffic using it.

38. The prevailing opinion that no pavement is a good one unless when once laid it will take care of itself is erroneous; *there is no such pavement.* All pavements are being constantly worn by traffic and the action of the atmosphere, and if any defects which appear are not quickly repaired they soon become unsatisfactory and are destroyed. To keep them in good repair incessant attention is necessary and is consistent with economy. Yet claims are made that particular pavements cost little or nothing for repairs, simply because repairs are not made, while any one can see the need of them.

39. *Third.*—Any pavement, to be considered as properly cared

for, must be kept dustless and clean. While circumstances legitimately determine in many cases that streets must be cleaned at daily, weekly, or semi-weekly intervals, the only admissible condition for the purpose of analysis of street expenses must be that of like requirements in both or all cases subjected to comparison.

40. The cleansing of pavements both as regards its efficiency and cost depends (1) upon the character of the surface; (2) upon the nature of the material of which they are composed. Block pavements present the greatest difficulty; the joints can never be perfectly cleansed. The order of merit for facility of cleansing is (1) asphalt, (2) brick, (3) stone, (4) wood, (5) macadam.

41. *Fourth.*—The annual cost for service is made up by combining several items of cost incidental to the use of the pavement for traffic; for instance, the limitation of the speed of movement, as in cases where a bad pavement causes slow driving and the consequent loss of time; or cases where the condition of a pavement limits the weight of the load which the horse can haul, and so compels the making of more trips or the employment of more horses and vehicles; or cases where it causes greater wear and tear of vehicles, of equipage, and of horses. If a vehicle is run 1500 miles in a year and its maintenance costs $30 a year, then the cost of its maintenance per mile travelled is two cents. If the value of a team's time is, say, $1 for the legitimate time taken in going one mile with a load, and in consequence of bad roads it takes double that time, then the cost to traffic from having to use that one mile of bad roadway is $1 for each load. The same reasoning applies to circumstances where the weight of the load has to be reduced so as to necessitate the making of more than one trip. Again, bad pavements lessen not only the life-service of horses, but also the value of their current service. The unit of these accounts is obtained by first finding the cost per mile of distance travelled, which cost divided by 5,280 and multiplied by the unit of area gives the desired result.

42. *Fifth.* **Consequential Damages.**—The determination of consequential damages arising from the use of defective or unsuitable pavements involves the consideration of a wide array of diverse circumstances. Rough-surfaced pavements, when in their best condition, afford a lodgment for organic matter composed largely of the urine and excrement of the animals employed upon the road-

way. In warm and damp weather these matters undergo putrefactive fermentation and become the most efficient agency for generating and disseminating noxious vapors and disease-germs, now recognized as the cause of a large part of the ills afflicting mankind. Pavements formed of porous materials are objectionable on the same if not even stronger grounds.

43. Pavements productive of dust and mud are objectionable, and especially so on streets devoted to retail trade. If this particular disadvantage be appraised at so small a sum per lineal foot of frontage as $1.50 per month, or six cents per day, it exceeds the cost of the best quality of pavement free from these disadvantages. Rough-surfaced pavements are noisy under traffic and insufferable to nervous invalids, and much nervous sickness is attributable to them. To all persons interested in nervous invalids this damage from noisy pavements is rated as being far greater than would be the cost of substituting the best quality of noiseless pavement; but there are, under many circumstances, specific financial losses, measurable in dollars and cents, dependent upon the use of rough, noisy pavements. They reduce the rental value of buildings and offices situated upon streets so paved, offices devoted to pursuits wherein exhausting brain-work is required. In such locations quietness is almost indispensable, and no question about the cost of a noiseless pavement weighs against its possession. When an investigator has done the best he can to determine such a summary of costs of a pavement, he may divide the amount of annual tonnage of the street traffic by the amount of annual costs and know what number of tons of traffic are borne for each cent of the average annual cost, which is the crucial test for any comparison, as follows:

(1) Annual interest upon the first cost........................$
(2) Average annual expense for maintenance and renewal......
(3) Annual cost for custody (sprinkling and cleaning).........
(4) Annual cost of service and use .. ..
(5) Annual cost of consequential damages....................
Amount of average annual cost..............................
Annual tonnage of traffic. ....
Tons of traffic for each cent of cost... ....

44. Gross Cost of Pavements.—Since the cost of a pavement depends upon the material of which it is formed, the width of the roadway, the extent and nature of the traffic, the condition of

repair and cleanliness in which it is maintained, it follows that in no two streets is the endurance or the cost the same, and the difference between the highest and lowest periods of endurance and amount of cost is very considerable.

The comparative cost of various street pavements in Liverpool, including interest on first cost, sinking fund, maintenance, and cleaning, when reduced to a uniform standard traffic of 100,000 tons per annum for each yard in width of the carriage-way, is given by Mr. Deacon as follows:

	Per Square Yard per Annum.
Block pavements of hard granites	$0.23
" " " softer "	0.28
Bituminous concrete	0.35
Wood pavement	0.53
Macadam, on pitch foundation	0.71

Taking the standard of traffic at 40,000 tons per annum, for each yard in width the cost for the last three pavements is:

Bituminous concrete	0.27
Wood	0.41
Macadam	0.47

Asphalt may be placed between wood and bituminous concrete, in the above order. These comparisons show the high cost of a macadamized surface in a street where traffic is great; and however well it may be maintained, it is much dirtier and dustier than any other pavement, though it is superior to them all in safety, and to block pavements in the matter of noise.

Table III shows the approximate comparative gross cost of various pavements in the United States for a period of fifty years, the pavement at the end of that period to be in as good condition as when first laid.

45. Traffic Census.—Comparison of pavements in respect to their gross cost can be effected only by comparing the gross traffic tonnage which each will bear for a unit of cost. As this can be ascertained only by direct observation, it is desirable that engineers in charge of roads and streets find out accurately the traffic tonnage, the amount of force required to draw a unit of weight over different surfaces in like condition, the cost of maintaining different coverings during a given period under a unit of traffic tonnage, the

TABLE III.

COMPARISON OF THE GROSS COST OF PAVEMENTS FOR A PERIOD OF 50 YEARS.

	Cost per Square Yard.			
	Granite Block.	Asphalt.	Wood.	Brick.
Foundation, 6 in. concrete	$1.00	$1.00	$1.00	$1.00
Materials, labor, etc	3.25	2.50	1.40	1.80
Total first cost	4.25	3.50	2.40	2.80
Interest on materials and sinking fund, 50 yrs. @ 4 %	26.00	20.00	11.20	14.40
Interest on foundation @ 4 %	2.00	2.00	2.00	2.00
Maintenance, 50 years	2.50	4.50	7.50	2.50
Cleaning, etc., 50 years	5.00	1.00	6.00	2.50
3 renewals of surface @ $3.25	9.75	....	....	....
5 " " @ 2.50	....	12.50	....	....
12 " " @ 1.40	....	....	16.80	....
8 " " @ 1.80	....	....	....	14.40
Cost of service (estimated at)	30.00	10.00	20.00	15.00
" " consequential damages (" ")	10.00	1.00	1.50	2.00
Total	89.50	54.50	67.40	55.60
Less value of foundation	1.00	1.00	1.00	1.00
	88.50	53.50	66.40	54.60
Less value of old material	1.00	.10	....	.25
÷ 50)	87.50	53.40	66.40	54.35
Annual gross cost	1.75	1.068	1.33	1.087

relative safety of different surfaces, and the damage done to vehicles and horses by different pavements. These items should be carefully observed and recorded. As the amount of travel is variable, the observations should be made for a certain period on consecutive days, and should be repeated at different seasons of the year.

46. The most extensive observations on this subject in the United States were made under the direction of Capt. F. V. Greene, member of the American Society of Civil Engineers. The method of observing and recording was as follows: "The observations were made on six consecutive days (Sundays omitted) at the same place, and were continuous from 7 A.M. to 7 P.M., except when darkness prevented. No addition was made for this omission, nor for night traffic."

The printed instructions issued to each observer contained the following rules as a guide in estimating weights:

Less than 1 *ton.*

1-horse carriages, empty or loaded.
1-horse wagons, empty or light loaded.
1-horse carts, empty.

Between 1 *and* 3 *tons.*

1-horse wagons, heavy loaded.
1-horse carts, loaded.
2-horse wagons, empty or light loaded.

Over 3 *tons.*

Wagons and trucks drawn by two or more horses and heavy loaded.

"Special note will be made, in the column of Remarks, of any unusually heavy loads, such as 6-horse trucks loaded with stone or iron, and an estimate given of their weight."

The weight and number of the horses was disregarded, because Capt. Greene wished to make comparison with English reports in which their weight was disregarded. *Their weight should be included in all observations, as the action of their feet is an important factor in the wear of pavements.*

47. Capt. Greene assigned the following weights to each class of vehicles:

Light-weight vehicles one-half ton each, including their load; medium weight two tons, and the heavy weight four tons.

The weight to be assigned to each class of vehicles had better be ascertained by occasionally weighing a typical vehicle and its load. The weight of horses may be taken at one-half ton each.

48. Form of Traffic Census.

TRAFFIC CENSUS

of........ ....Street.
Class of pavement..
Condition...
Width between curbs ....
Date of observation...
State of the weather..
Temperature...
Name of observer...

Classification of Vehicles.	Hours of Observation.						
	6 to 7.	7 to 8.	8 to 9.	9 to 10.	10 to 11.	11 to 12.	12 to 1.
1-horse light							
1- " loaded							
2- " light							
2- " loaded							
3- " light							
3- " loaded							
4- " light							
4- " loaded							
Led horses, No. of							
Totals							
Number of falls							
Remarks							

49. To obtain tonnage, multiply the total number of vehicles in each class by the weights assigned to that class, and adding together the products the total vehicular tonnage is ascertained, which divided by the width between curbs and the number of days of observation gives the average daily tonnage per foot of width.

Under Condition note the state of repair and cleanliness; whether the surface is dry, damp, or greasy. Under Falls note the kind, whether on knees, haunches, or complete, and if possible the cause.

"The average tonnage per vehicle is an almost infallible indicator of the character of the street, i.e., whether devoted to residential or business purposes. It ranges from 0.68 tons on Fifth Avenue, New York City, to 2.08 tons on a portion of Wabash Avenue, Chicago. The same character is indicated by the proportions of light and heavy vehicles in the street. On Fifth Avenue, New York, for instance, 91% of all the vehicles weigh less than one ton, while on Wabash Avenue only 25% of them have so little weight. The general average for all cities is as follows: Less than 1 ton, 67%; between 1 and 3, 26%; more than 3 tons, 7%. The average tonnage per foot of width in each city, so far as here observed, varies from 151 in New York to 30 in Buffalo, and the general average is 77. For all the cities observed the average daily tonnage per foot of width is 77, and varies from 273 tons on Broadway, New York, to 7 tons on a granite street in St. Louis. The average weight per vehicle is, for all cities, 1.15 tons. The average width of the streets between curbs is 44 feet."

In London the traffic on some of the asphalt- and wood-paved streets exceeds 400 tons per foot of width per day.

In Liverpool granite-block pavements sustain a daily traffic tonnage per foot of width of from 400 to 500 tons.

The comparative rank of pavements in the order of their merit is shown in Table IV.

TABLE IV.

COMPARATIVE RANK OF PAVEMENTS, NAMED IN THE ORDER OF THEIR MERIT.

Order of Merit.	Durability.	Serviceability.	Hygienic Fitness.	Service on Grades.	Gross Annual Cost.	Facility for Cleansing.
1	Granite	Asphalt	Asphalt	Granite	Asphalt	Asphalt
2	Asphalt	Brick	Brick	Brick	Brick	Brick
3	Brick	Wood	Granite	Wood	Wood	Granite
4	Wood	Granite	Wood	Asphalt	Granite	Wood

50. Guaranteeing Pavements.—To secure pavements that shall be durable and serviceable, the municipal authorities often require the contractors to guarantee their pavements for a term, usually, of five years, under provisions calling for maintenance in good condition during that period of time and for final delivery in good order. Such contracts involve two kinds of service, that of construction, and of maintenance for a limited period. In the latter the conditions are exacted indiscriminately alike on streets with heavy traffic and on those with very light traffic, and thereby become sometimes burdensome, unless the same contractor paves so many streets of all kinds as to correct the inequality by securing of fair average traffic condition. The correct policy to pursue in contracting for maintenance would be to measure the service of the pavement by the tonnage rather than by the years. To do so equitably the city needs information about the traffic, which it can obtain only by having a traffic census taken as described in Art. 45.

51. Many contracts for street pavements in some European cities have provided for the construction and the maintenance of the pavements for long terms, say of twenty years, payments to be made in equal annual instalments throughout the term. Such arrangements appeared at first to be very favorable, owing to the first payments being so much less than they otherwise would be for the whole cost of construction. The pro-rata annual payments

provided for the interest and risks of various kinds, with contractors' profits thereon, in addition to the direct outlays for construction and repairs, so that the final outcome was unsatisfactory to both parties to the contract. The prevailing custom in this country is to pay the cost of constructien of a pavement as soon as completed. Two methods of meeting the expense of maintenance are followed. In one the municipality meets the annual requirements as they occur, and in the other, under contract for a term, say, of ten or twenty years, the contractor, for equal annual payments, is required to keep the pavement and turn it over to his successor in good condition at the expiration of the contract.

52. This annual payment has to cover the contingency of the contractor's being at the expense of completely renewing the pavement. The equal annual amounts paid on contracts for maintenance, as just explained, include two funds, one of repair accounts and the other a sinking fund, intended to meet the cost of renewing the pavement, which must be done if the contract is for a long term of years.

53. If an attempt is made to separate, for each year, the proportion of the annual payment which should provide for each of the two purposes, it would be found that the earlier years would be contributing little or nothing for repairs, as, the pavement being new, they would not be required, but the proportion so applied would increase gradually, and at last consume nearly all the annual payment.

54. The justification of contracts for the continuous maintenance of pavements is in the advantage gained from having some one admittedly responsible for their condition and more amenable to discipline than are city officials for neglect. With this consideration in mind each community can determine whether it is to its advantage or not to contract for such maintenance.

55. Destruction of Pavements.—The most serious cause of the destruction of street pavements is the frequency with which they are torn up for the introduction and repairing of underground pipes, and no pavement can be designed which will withstand such frequent disturbance. The only radical remedy for this evil is a very costly one in its first inauguration, but it is one that would be economical in the end, and that is a subway or series of subways under our roadways.

56. The amount of money wasted in continually opening up the streets, digging, bracing, and refilling, is a considerable item, not counting the interference with travel and business, and would be sufficient to cover the interest on the cost of the subways. The waste, being distributed through many companies, is not sufficiently felt to cause a reconstruction. The streets of New York were opened 27,088 times in 1890 by the gas, steam-supply, and other companies.

57. Under the best municipal administrations of Europe neither corporations nor individuals are permitted to disturb the pavements. All removals and restorations are done by the city's own employés, upon the deposit, by the parties who require the streets to be opened, of a sufficient sum to cover the expense for each piece of paving done, at a fixed price per yard according to the kind of pavement.

Moreover, interference with the pavements is of rare occurrence, for the companies having pipes underground are required to thoroughly examine and reinstate their mains and services concurrently with the paving of a street, of the execution of which due notice is given them by the city. Such regulations are quite practical, and there can be no hardship in requiring American companies to pay for like work.

It is stated that in Victoria Street, one of London's busiest thoroughfares, not a single stone has been disturbed from the carriage-way in twenty-five years. This street, as well as many others, has a subway in which are contained the gas and water pipes and upwards of six conduits for telegraph and electric wires.

CHAPTER II.

MATERIALS EMPLOYED IN THE CONSTRUCTION OF PAVEMENTS.

58. Selection of Paving Material.—The materials most commonly used for pavements are stone in the form of blocks and broken fragments: wood in the form of blocks and plank, asphalt in two forms,—sheet and block,—and clay in the form of brick.

59. In considering the relative fitness of the various materials, the following physical and chemical qualities must be sought for:

(1) Hardness, or that disposition of a solid which renders it difficult to displace its parts among themselves.

(2) Toughness, or that quality by which it will endure light but rapid blows without breaking.

(3) Ability to withstand the destructive action of the weather, and probably some organic acids produced by the decomposition of excretal matters, always present upon roadways in use.

(4) The porosity, or water-absorbing capacity, is of considerable importance. There is perhaps no more potent disintegrator in nature than frost, and it may be accepted as fact that of two rocks which are to be exposed to frost, the one most absorbent of water will be the least durable.

60. Breaking and Crushing Tests possess no definite value in determining upon the fitness of a material for paving purposes. It is an elementary fact in mechanics that a body may bear an enormous crushing strain gradually applied and yet be readily broken by a smart blow from a light hammer. Taking the ascertained breaking and crushing strains as lying between 3½ and 7 tons per square inch, it may be safely said that no such strains are ever brought to bear upon any single inch of roadway in practice, not

even during the passage of a ten-ton roller. The direct pressure or strain as applied in a testing-machine has no resemblance to the quick blows of horses' hoofs, much less to the abrading action of wheels.

61. Methods of Testing Durability.—The only true test of the fitness of any material for paving is by an experimental trial upon a certain length of roadway under a unit of traffic. The "Rattler" tests now much employed to test the quality of bricks for paving do not fairly represent the condition of the materials in the pavement; in the latter the material is supported on all sides but one, and is subjected to pressure and percussion on this side, while in the "Rattler" tests the materials are thrown into violent collision with large pieces of iron weighing anywhere from five to fifteen pounds. It is evident that under this treatment the corners of the material will readily succumb, and the wear in consequence will be much greater and of a different nature than it would be under actual conditions. The methods adopted for testing any material should represent as nearly as possible the requirements of practical use.

62. The following plan of testing the comparative value of paving-stones is adopted at the Paris Laboratory for Testing Materials. While it may be questioned whether this method is superior to the "Rattler" test, it indicates foreign appreciation of the fact that the "Rattler" test is not what it should be. The stone or other samples are clamped to a horizontal plate revolving round a vertical spindle and brought to bear with equal pressure against a similarly disposed revolving plate of cast-iron. Along with the samples to be tested is placed a specimen of the standard material, which is Yvette sandstone. The coefficient of wear is the proportion between the volumes worn, which is ascertained by weighing the specimens and determining the volume from this weight. The coefficient for first-class materials is from 1 to 1.40, and for second-class materials from 1.40 to 2.40. If the wear is greater than that represented by the coefficients, the material is rejected.

63. At St. Louis, Mo., some years ago, strips of different pavements 22 inches wide and 8 feet long were laid down as a test, and a two-wheeled cart with tires 2½ inches wide, and loaded to two tons, or 800 pounds per inch width of tire, was rolled back and forth by machinery. The heaviest traffic at that time in St. Louis was 75

tons per day per foot of width, and the average for business streets was 35 tons. Estimating the effect of horses' shoes at one third of this amount, 50 tons per foot were taken as a standard. The samples were weighed before and after testing, and were subjected to an amount of travel by the above cart equivalent to eight and one half years on the street.

The total abrasion of the fire-brick pavement was 9%, or a depth of ⅜ of an inch, but about one half of the bricks were broken. Asphaltum blocks under the same test wore 14%, and but one was broken. Broken stone lost 1% under a traffic of 12.7 tons per foot of width. Broken stone and sand lost 1% under 16 tons per foot. Limestone blocks lost 1% under 4400 tons per foot of width. Wood blocks lost 1% under 12,900 tons per foot, and the granite blocks lost 1% under 70,000 tons.

The action of the elements was not taken into consideration; it would undoubtedly increase the wear of the several materials.

64. Absorptive Power of Stones, etc.—All materials absorb water to a greater or less extent, and their durability is much affected by their absorbing capacity. This capacity depends largely on the density, a dense stone absorbing less than a light and more porous one. The absorbing capacity is a matter of much importance, especially in cold climates. The water absorbed, on freezing, tends by its expansion to disintegrate the stone. It has been said that the act of freezing is equivalent to the blow of a ten-ton hammer on every square inch of surface. Whether this be so or not, the continued expansion and contraction of a porous stone is quite sufficient to disintegrate it, and this disintegration will be the greater the more water the stone contains.

TABLE V.

ABSORPTIVE POWER OF STONES, ETC.

	Percentage of water absorbed.
Granites	0.066 to 0·155
Marbles	0.08 " 0.16
Limestones	0.20 " 5.00
Sandstones	0.41 " 5.48
Brick, common	2.00 " 25.00
" paving	0.15 " 8.00
Mortars	10.00 " 50.00
Wood	0.16 " 9.00
Asphalt	Impervious

Stones that have already begun to decompose absorb a much larger quantity of water than those fresh from the quarry, and decay will be more rapid. Other things being equal, the less the absorption the better the stone or brick.

65. Description of Materials.—Granite is an unstratified or igneous rock, composed of silica or quartz, feldspar, and mica. In addition to these essential constituents, one or more accessory minerals may be present; the more commonly occurring are hornblende, pyroxene, epidote, garnet, tourmaline, magnetite, pyrite, and graphite. And the character of the rock is often determined by the presence of these accessory constituents in quantity.

Granite varies in texture from very fine and homogeneous to coarse porphyritic rocks in which the individual grains are an inch or more in length. The color is also dependent upon the minerals present: if the feldspar is the orthoclase (potash-spar), it communicates a red color; the soda-spar produces gray. The mica also plays an important part in the modification of color: if it is the white muscovite, it produces no change; but if the black biotite mica be present, it modifies the color accordingly. Hornblende gives a dark mottled appearance; pyroxene as augite also gives a darker appearance; epidote communicates a green color.

The durability of the granites is closely related to their mineralogical composition. The presence or absence of certain species influences the hardness and homogeneous nature of the stone. Although popularly regarded as the most durable stone, there are some notable exceptions.

The quartzose, feldspathic, and micaceous granites are unsuitable for paving purposes. The quartzose are too brittle, the feldspathic are too easily decomposed. When the feldspar is in excess the granite rapidly decays and disintegrates in consequence of the action of air and water on the feldspar, the potash of which seems to be removed, and the residue falls into a white powder composed chiefly of silica aud alumina. The micaceous are too easily laminated.

The term "granite" as popularly used is not restricted to rock species of this name in geological nomenclature, but includes what are known as gneisses (foliated and bedded granites, syenite, gabbro, and other crystalline rocks whose uses are the same); in fact, the similar adaptability and use have brought these latter

species into the class of granites. The term is often improperly applied to the diabases or trap-rocks.

66. Syenite differs from granite in having more hornblende, with some plagioclase, feldspar, and mica, and little or no quartz. (It is called syenite because it was first found in the island of Syene in Egypt.) It is massive and its occurrence is like that of granite. It furnishes the best material for paving-blocks, and is better in proportion to the darkness of color and the predominance of hornblende.

67. The Sioux Falls stone, much used for paving in the West, is a quartzite, close-grained, non-absorbent, and frost-proof. It does not break evenly as granite and sandstone.

68. The gneiss, quartz, and silicious rocks, though hard, are too brittle and deficient in toughness for paving purposes.

69. Table VI. shows the specific gravity, weight, and resistance to crushing of various granites.

TABLE VI.

SPECIFIC GRAVITY, WEIGHT, AND RESISTANCE TO CRUSHING OF VARIOUS GRANITES.

Localities.	Specific Gravity.	Average Weight, pounds per cubic foot.	Resistance to Crushing, pounds per square inch.
Kirtland Rocks, Conn.	2.66	166	35,000
Lord's Island, Conn.			24,000
Chaumont Bay, N. Y.	2 65	162.2	22,700
Mystic River, Conn.	2.63	164.4	22,250
Sharkey's Quarry, Me.	2.72		22,125
Richmond, Va.			21,250
Huron Island, Mich.			20,650
Rockport, Mass.	2.61	163.2	19,750
Port Deposit, Md.			19,750
Quincy, Mass.	2.66	166.2	19,500
Duluth, Minn.			19,000
Hurricane Island, Me.	2.67	166.9	15,000
Mount Sorrel, England	2.67	167	12,800
Bay of Fundy, Canada			11,916
Aberdeen, Scotland (gray)	2.62	163	10,900
" " (red)	2.62	165	
Dublin, Ireland			10,450
New Haven, Conn.			9,750
Cornish, Wales	2.66	166	6,300
Patapsco, Md.	2.64	163	5,340

70. Table VII shows the amount of production and value of granite for street purposes throughout the United States for the year 1889. From this table it appears that the number of blocks used for paving amounted to nearly 62,000,000; that the value per thousand varies from $32.22 in Wisconsin to $78.67 in Delaware.

TABLE VII.

PRODUCTION AND VALUE OF GRANITE FOR STREET USES IN 1889.*

States.	Cubic feet, including Paving-blocks.	Value, including Paving-blocks.	Value per cubic foot.	Number of Paving-blocks.	Value of Paving-blocks.	Value per thousand.
California.......	3,284,232	$551,613	$0.17	7,303,321	$297,236	$40.70
Colorado........	1,100	230	0.21	....	....	......
Connecticut.....	567,860	109,261	0.19	761,100	40,683	53.45
Delaware.......	155,500	67,202	0.43	104,333	8,208	78.67
Georgia.........	658,603	250,634	0.38	1,599,952	84,951	53.10
Maine..........	3,736,541	927,949	0.25	17,704,915	824,113	46.55
Maryland.......	1,051,010	125,958	0.12	286,950	10,310	35.93
Massachusetts...	1,475,093	466,147	0.32	6,106,016	378,627	62.01
Minnesota.......	338,640	141,554	0.42	1,239,000	68,045	54.92
Missouri........	871,209	216,986	0 25	4,323,130	216,986	50.19
New Hampshire.	1,157,992	252,256	0.22	2,043,739	87,569	42.85
New Jersey.....	2,089,796	236,310	0.11	3,999,912	168,555	42.14
New York......	247,902	51,062	0.21	587,120	26,962	45.92
North Carolina..	221,820	42,605	0.19	775,000	34,200	44.13
Oregon...... ...	117,400	30,200	0.26	587,000	30,200	51.45
Pennsylvania....	1,996,486	368,323	0.18	3,836,127	241,793	63.03
Rhode Island....	213,477	65,817	0.31	781,765	45,817	58.61
South Carolina..	94,489	34,016	0.36	....	....	....
South Dakota...	601,000	170,695	0.28	3,017,500	170,694	56.57
Vermont........	231,128	48,323	0 21	883,096	45,643	51.69
Virginia	286,946	75,925	0.26	342,895	18,505	53.97
Wisconsin	1,285,000	223,825	0.17	5,540,000	179,075	32.32
Total.......	20,683,244	$4,456,891	$0.22	61,822,871	$2,978,172	$48.17

* 11th U. S. Census.

71. Value of Granite Blocks.—In the most important States which produce paving blocks, namely, California, Maine, Massachusetts, Missouri, New Jersey, and Pennsylvania, the value varies from $40 to something over $60 per thousand. The variation in the price for these States, in all of which the production of paving-blocks has been going on for some time, is due to the quality of the stone used for these purposes, and also to the special care observed in trimming blocks to certain definite sizes. In some localities surface rock of inferior quality is broken up into paving-blocks.

which are sold at low prices. In a number of cities considerable care is taken by the municipal authorities in the selection of the granite for paving material. This care is exercised both with reference to the quality of the stone and to invariability of size, and consequently the price paid is in some cases markedly higher than that paid in other cities more indifferent in regard to the material employed.

72. The following list is presented for the purpose of showing the various uses of granite for street and road construction:

Paving-blocks.	Basin-heads.
Curbing.	Crossing-stones.
Flagging.	Gutter-stones.

Crushed for artificial stone; broken for concrete.

73. Manufacture of Granite Paving-blocks.—The manufacture of paving-blocks varies in many of its details from the ordinary methods of granite-cutting. The high skill and fine workmanship of the stone-cutter are not needed, but a quickness in seeing and taking advantage of the directions of cleavage, as well as a deftness in handling the necessary tools, is requisite.

The tools used for making blocks are knapping-hammers, opening-hammers, reels, chisels, and for initial splits drills, wedges, and half-rounds. When the block-maker quarries his own stock it is called "motion work," and the same process is used as in quarrying stone for other purposes, except that, as large blocks are not required, most of it can be done with plug and feather.

Slabs, having been split out in the usual manner to sizes that may be easily turned over and handled by one man, are subdivided into pieces corresponding approximately to the dimensions of the required blocks. This is done by striking repeated blows upon the rock along the line of the desired break with heavy knapping and opening hammers. When a break is to be made crosswise the grain, it is frequently necessary to chisel a light groove across one face, and commonly across the adjacent sides, to guide the fracture produced by striking on the opposite surface with the opening-hammer. Good splits can, however, be made along either the rift or grain by the skilful use of the opening-hammer alone. Blocks broken out in the manner described are trimmed and finished with the reel, which is a hand-hammer having a long, flat steel head attached to a short handle. Block-makers become very expert in

the use of this tool, and without making any measurements turn out in a surprisingly short time a large number of blocks. In Maine, which is far ahead of any other State in the number of blocks made, the entire product of many quarries is used for this purpose exclusively. This is also the case in California, which comes second, though the blocks are manufactured chiefly from the surface "boulders" or detached masses of basalt so common in Sonoma County. Other quarries, however, in various parts of the country utilize only the "grout," small or irregular-shaped pieces, for making paving-blocks, and haul the stock to the breakers, who work in sheds; but the greatest number of blocks are made on the spot where the rock is quarried, the workmen being protected during the hottest months by a temporarily spread canvas fly.

Blocks are counted as they are thrown into the cart which is usually needed to haul them to the shipping point. Several paving-block quarries in Maine are situated on steep mountain-slopes so near water communication that blocks may be slid in long board chutes from the quarry directly into the hold of the vessel used for their transportation.

Paving breakers seldom work by the day, but are paid a certain sum per thousand for making the blocks; the price paid in 1889 ranging from $22 to $30 according to the size of block made, kind of stone used, locality, and whether the tools were furnished and the blocks quarried by their employers. Workmen using their own tools are commonly paid one dollar more per thousand for the blocks made; and when they quarry the stock they use, from $2 to $5 per thousand is allowed in addition.

74. Sandstones are rocks made up of grains of sand which are cemented together by silicious, ferruginous, calcareous, or argillaceous material. From the nature of the cementing material the rocks are variously designated as ferruginous, calcareous, etc. In most cases the cementing material determines the color. The various shades of red and yellow depend upon the iron oxides. The purple tints are said to be due to oxide of manganese. The gray and blue tints are produced by iron in the form of ferrous oxide or carbonate.

75. The hardness, strength, and durability depend upon the nature of the cementing material. If the cementing material be one which decomposes readily, as in the argillaceous and calcareous varieties, the whole mass is soon reduced to sand.

76. Sandstones are widely distributed, and they represent the geological periods, from the oldest to the most recent f tions.

77. The sandstones obtained from the Upper Silurian ar Lower Carboniferous formations are much used in the form of l for street paving in the Lake and Western cities. They are du and do not become smooth or slippery when wet, but in the of fragments for broken stone roads they are useless.

78. **Hudson River Bluestone.**—The term "Hudson River stone" is used to designate the blue, fine-grained, compact even-bedded sandstone which is so largely employed for fla and curbing in the cities and towns of New York and neighb States.

The color is predominantly dark gray and hence (more by trast with the red sandstone) a "bluestone."

In texture the range is from the fine shaly or argillaceo the highly silicious and even conglomerate rock.

The best bluestone is rather fine-grained and not very p laminated, and its mass is nearly all silica or quartz which mented tegether by a silicious paste and contains very little laceous matter.

It is so compact as not to absorb moisture to any extent hence soon dries after rain or ice; it has the hardness to abrasion and wears well; it is even-bedded and thus presents a

TABLE VIII.

ANALYSIS OF SANDSTONE.

Kind of Stone.	Locality.	Silica.	Alumina.	Iron Oxides.	Manganese Oxide.	Lime.	Magnesia.	Potash.	Soda.
		p. ct.	p. ct.	p. ct.	p. ct.	p. ct.	p. ct.	p. ct.	p. ct
Manyard......	E. Long-	79.38	8.75	2.43	..	2.57	....	4.	08
Worcester....	meadow,	88.89	5.95	1.79	0.41	0.27	....	0.	86
Kibbie........	Mass.	81.38	9.44	3 54	0.11	0.76	0.28	.....	.....
Brownstone..	Portland, Conn.	69.94	13.15	2.48	0.70	3.09	Trace	3.30	5.43
Sandstone....	Stony Pt., Mich.	84.57	5.90	6.48	....	....	0.68	Unde	ter'd
Quartzite.....	Pipestone, Minn	84.52	12 33	2.12	....	0.31	Trace	0.11	0.34
Buff..........	Amherst, Ohio.	97.00	.....	1.00	....	1.15	.. .	0.	64
Berea.........	Berea, Ohio.	96.90	......	1.68	....	0.55	..	0.	55
Euclid Bluest.	Euclid Co., Ohio.	95.00	2.50	1.00	....	....	....	.....	.....
Columbia.....	Columbia, Ohio.	96.50	.. ..	....	....	1.00	..	0.	50
Red...........	Laurel Run, Pa.	94.00	Trace	1.90	....	1.10	1.00	.....	....
Elyria........	Grafton, Ohio.	87.66	1.72	3.52	....	0 17	0.20	.....	.....
Sandstone....	Fond du Lac, Mn.	78.24	10.88	3.83	....	0.95	1 60	1.67	0.06

smooth natural surface, and it has a grain which prevents it from becoming slippery; it is not materially affected by freezing and thawing; it is strong and not apt to get broken if well laid.

79. **Commercial Names of Sandstone.**—The commercial names of sandstone are usually obtained from places where it is quarried, as, Berea, Grit, Medina, etc.

80. Table VIII on the opposite page, giving analyses of sandstone from a number of localities, will serve to indicate its general composition.

81. The specific gravity, weight, and resistance to crushing of various sandstones is given in Table IX. The amount of production and value of sandstone for street purposes in the United States in 1889 is given in Tables X and XI.

TABLE IX.

SPECIFIC GRAVITY, WEIGHT, AND RESISTANCE TO CRUSHING OF VARIOUS SANDSTONES.

Localities.	Specific Gravity.	Average Weight, pounds per cubic foot.	Resistance to Crushing, pounds per square inch.
Potsdam (red), N. Y.	2.60	162.28	42,804
Medina, N. Y.			17,725
Malden (bluestone), N. Y.	2.75	171.47	
Warsaw (bluestone), N. Y.	2.68	167.10	
Albion, N. Y.			13,500
Craigleith, Scotland	2.45	153	5,287
Belleville, N. J.	2.56	159.67	11,700
Kasota, Minn.			11,675
Seneca, Ohio			10,500
Berea, Ohio	2.57	160.06	10,250
Little Falls, N. Y.			9,850
Dorchester, New Brunswick			9,412
Vermilion, Ohio			8,850
Massillon, Ohio			8,750
Cleveland, Ohio			7,910
Abroath (pavement), England	2.47	155	7,884
Marquette, Mich.	2.53	158.17	7,450
Middletown (Portland), Conn.	2.62	163.43	6,950
North Amherst, Ohio			6,650
Oxford (bluestone), N. Y.	2.71	168.9	13,472
Fond du Lac, Wis.			6,250
Bristow, Va.	2.61	163	
Yorkshire, England	2.51	157	5,714
Warrensburg, Ohio			5,000
Haverstraw, N. Y.			4,350
Derby Grit, England	2.4	150	3,100
Cheshire (red), England	2.15	133	2,185
Nova Scotia	2.62	163.50	

TABLE X.

PRODUCTION AND VALUE OF SANDSTONE FOR STREET USES IN 1889, BY STATES AND TERRITORIES.*

States and Territories.	Cubic Feet.	Value.	Value per cubic foot.
Arkansas	27,160	8,215	0.30
California	100	200	2.00
Colorado	1,926,464	509,955	0.26
Connecticut	40,500	2,250	0.06
Idaho	....	....	...
Illinois	3,200	50	0.02
Iowa	8,840	880	0.10
Kansas	452,015	132,188	0.29
Kentucky	13,900	1,600	0.12
Maryland	40,320	2,045	0.05
Massachusetts	501,221	40,471	0.08
Michigan	2,496	550	0.22
Minnesota	51,930	38,200	0.74
Missouri	6,533	2,512	0.38
New Mexico	10,000	3,000	0.30
New York	2,864,366	459,158	0.16
Ohio	1,603,614	430,552	0.27
Pennsylvania	854,907	175,062	0.20
West Virginia	42,075	23,274	0.55
Florida, Georgia, Nevada, Rhode Island, Vermont	13,865	2,660	0.19
Total	8,463,506	$1,832,822	$0.22

* 11th U. S. Census.

TABLE XI.

PRODUCTION AND VALUE OF "BLUESTONE" FOR STREET USES IN 1889.

States.	Cubic Feet.	Value.	Value per cubic foot.
New Jersey	15,649	8,550	0.55
New York	2,357,724	475,403	0.20
Pennsylvania	786,513	265,959	0.34
Total	3,159,886	$749,912	$0.24

82. **Limestone.**—Limestone is essentially carbonate of lime, but it always contains some additional constituent; the more commonly occurring impurities or accessory matters are silica in the form of

quartz, clay, iron, magnesia, etc. And limestones are said to be silicious, argillaceous, ferruginous, magnesian, dolomitic, bituminous, etc., according as they contain one or another of these constituents. Other foreign mineral matter may be found in them, and in such quantity as to give character to the mass.

In color there is a wide variation, depending upon the impurities; it ranges from the white of the more nearly pure carbonate of lime through gray, blue, yellow, red, brown, and to black.

The texture also varies greatly; it may be coarse or fine. The terms *coarse-grained* and *fine-grained* are applied when the mass resembles sandstone in its granular aggregations. Other terms, as saccharoidal (like sugar), oolitic, crinoidal, etc., are also used to describe the texture. The state of aggregation of the constituent particles varies greatly, and the stone may be hard and compact, almost vitreous, or loosely cemented and crumbling with slight pressure, like sugar, or, again, like chalk, dull and earthy.

From this general statement of the range in composition and texture, it follows that there is an equally wide variation in hardness, strength, and durability of limestones. Some are hard and strong, surpassing in their resistance to crushing force many granites, and nearly as durable as the best sandstone; others are friable and fall to pieces under slight pressure, or they are disintegrated rapidly by atmospheric agents.

83. The limestones are used for flagging and curbing, being selected for these purposes on account of accessibility or cheapness. For broken-stone roads with light traffic the limestones are eminently suitable; they possess the quality of forming a mortar-like detritus which binds the stones together and enables them to wear better than a harder material that does not bind. For this purpose the most suitable ones are the silicious, magnesian, dolomitic, and bituminous.

84. The experience of all cities using paving-blocks of limestone is that it wears unevenly, and in a year or two the blocks are shivered and split by the action of frost.

Table XII shows the specific gravity, weight, and resistance to crushing of various limestones. Table XIII shows the production and value of limestone for street uses in 1889, by States and Territories.

TABLE XII.

SPECIFIC GRAVITY, WEIGHT, AND RESISTANCE TO CRUSHING OF VARIOUS LIMESTONES.

Localities.	Specific Gravity.	Average Weight, pounds per cubic foot.	Resistance to Crushing, pounds per square inch.
Joliet, Ill	...	...	16,900
Bardstown, Ky	2.69	168	16,250
North River, N. Y	2.71	169	13,425
Marblehead, Ohio	....	...	12,600
Glens Falls, N. Y	2.70	169	11,475
Marquette, Mich	....	...	8,050
Billingsville, Mo	....	...	7,250
Caen, France	....	...	3,650
Purbeck, England	2.6	162	9,160
Anglesea, "	....	...	7,579
Blue Lias "	2.467	154	......

TABLE XIII.

PRODUCTION AND VALUE OF LIMESTONE FOR STREET USES IN 1880, BY STATES AND TERRITORIES.*

	Cubic Feet.	Value.	Value per cubic foot.
Alabama	98,000	9,800	0.10
Arkansas	2,000	500	0.25
California	35,000	1,390	0.04
Illinois	10,221,892	505,576	0.05
Indiana	2,614,862	316,722	0.12
Iowa	1,707,931	53,641	0.03
Kansas	771,041	97,502	0.13
Kentucky	1,762,711	86,054	0.05
Maryland	145,670	6,750	0.05
Michigan	485,377	18,156	0.04
Minnesota	68,788	11,778	0.17
Missouri	11,542,723	670,351	0.06
Nebraska	1,926,469	86,643	0.04
New York	5,241,262	197,091	0.04
Ohio	7,236,981	183,235	0.03
Pennsylvania	2,042,804	72,512	0.04
Tennessee	14,500	3,400	0.23
Texas	67,750	32,278	0.48
Vermont	9,990	2,098	0.21
Virginia	7,560	190	0.03
Wisconsin	488,811	27,789	0.06
Total	46,491,622	$2,383,456	$0.05

* 11th U. S. Census.

85. The material called **Ligonier "Granite,"** which is extensively used for paving, etc., is a silicious limestone from localities

near Pittsburg, and is said to have a crushing strength of 23,000 pounds per square inch.

86. Trap-rock is the common name given to a large group of unstratified eruptive or igneous rocks. They are composed of feldspar (usually labradorite), augite, hornblende, and some magnetite and titanic iron.

The term *trap* is derived from *trappa*, a Swedish word for stair, because the rocks of this class frequently occur in large tabular masses rising one above the other like steps, as seen on the west shore of the Hudson River from Jersey City to Haverstraw. The various proportions and states of aggregation of the simple minerals, and their differences in external forms, give rise to many varieties —such as *dolorite*, which depends for its hardness upon silica and feldspar, and may be either light or dark colored. *Basalt* is one of the most common varieties; it is of a dark green, gray, or black color, is composed of augite and feldspar, very compact in texture and of considerable hardness, it often contains iron, whence the name *basalt*, an Ethiopian word for iron. *Greenstone*, another variety, is composed of hornblende and feldspar and is of a dark green color.

The trap-rocks are hard and tough, have no true cleavage, and break irregularly; they are difficult to work. But there is much variation in the stones of different localities. The rock of the Palisades in New Jersey splits easily into blocks, and has been extensively used for paving in New York, Brooklyn, and Jersey City, under the name of "Belgian block;" but since the introduction of granite for this purpose their use has considerably decreased.

The trap-rocks are exceedingly durable and eminently suitable for broken-stone roads, but for paving-blocks they are a failure.

87. Table XIV shows the crushing resistances, specific gravity, and weight of trap-rocks.

TABLE XIV.

CRUSHING RESISTANCE, SPECIFIC GRAVITY, AND WEIGHT OF TRAP-ROCKS.

Locality.	Resistance to Crushing, pounds per square inch.	Specific Gravity.	Weight of one cubic foot, pounds.
Staten Island, N. Y.	22,250	2.86	178 8
Jersey City Heights, N. J.	20,750 to 22,250	3.03	189.5
Palisades, N. J.	19,700		

88. Asphalt is the name given to mixtures of pure asphaltum with calcareous or silicious substances. It is of two kinds, natural and artificial. The natural asphalt consists of either limestone or sandstone impregnated with pure bitumen, whence the names *bituminous limestone, bituminous sandstone, rock asphalt,* etc. The artificial consists of a mechanical mixture of bitumen, sand, and crushed limestone.

89. Bituminous Limestones.—The asphalt employed for paving purposes throughout Europe is obtained from the bituminous limestones of France, Germany, Sicily, and Switzerland. At Seyssel in the department of Ain, France, at Ragusa, Sicily, at Limmer near Hanover, Germany, at Vorwohle in the Duchy of Brunswick, Germany, and in Val-de-Travers, Canton Neufchâtel, Switzerland, limestones are found impregnated quite uniformly with from 7 to 12 per cent of bitumen.

90. Table XV shows the constituents of the more important European bituminous rocks.

TABLE XV.

ANALYSIS OF EUROPEAN BITUMINOUS ROCKS.*

Constituents.	Val de Travers.	Seyssel.	Lobsan.	Sicilian.	Maestu.	Forens.
	per ct.	per ct.	per ct.	per ct.	per ct.	per ct.
Water and matter vol. at 212° F.[a]	[illegible]	[illegible]	[illegible]	[illegible]	0.40	0.25
Bitumen	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	2.25
Carbonate of lime	[illegible]	[illegible]	[illegible]	[illegible]	9.15	97.00
[illegible]		....	[illegible]	[illegible]	57.40	....
Alumina and peroxide of iron	[illegible]	[illegible]	[illegible]	[illegible]	4.35	0.15
[illegible]			[illegible]	....	....	....
Carbonate of magnesia	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0.20
[illegible]	[illegible]	[illegible]	....	....	11.35	0.05
Loss	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0.10
	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	100.00

* [illegible] M. Léon Malo.

[a] The [illegible] of the sample at the time [illegible] in the result.

[b] [illegible] proportion of [illegible] which was [illegible] determined.

[c] [illegible] combined with sulphur.

91. [illegible] two forms for paving [illegible] asphalt. The former

consists of the natural rock, which is first reduced to powder, then heated until softened, then spread upon the foundation while hot, tamped and rammed until compacted. This is the form chiefly used for carriage-way pavements in Europe. The liquid or mastic is a mixture of the natural rock (powdered) with asphaltum, the amount of the asphaltum varying with the richness of the rock. The two ingredients are softened by heating; to the heated mixture coarse sand, gravel, or shingle is added. The proportions in the mixture are about as follows: natural rock 60%, natural bitumen 4%, sand or gravel 36%. This material is more generally employed for sidewalks and floors.

92. Bituminous Sandstones are also found in Europe, but they are employed chiefly for the production of pure bitumen. They are found in several localities in the United States, but up to 1880 they were little used. Since that year they have been gradually coming into use as a paving material, and now upwards of fifty miles of streets in the Western cities are paved with them. They are used both in their natural condition and with the addition of bitumen and other materials.

93. The bituminous sandstones of the United States are prepared for street-paving uses as follows. The Gilsonite of Utah is first pulverized and mixed with petroleum; this mixture is heated, care being taken to keep the temperature below 500 degrees Fahr., as above that temperature the gilsonite will decompose. To the heated mass broken stone or gravel is added; it is then ready for the street. It is stated that a mixture of about 80% gravel makes a durable pavement.

94. The bituminous rock of Ventura and Santa Barbara counties, California, are heated and mixed with the sand of the locality where it is to be used; the sand is mixed with the rock in the proportion of from three to eight times by bulk of sand to one of rock.

95. The bituminous rocks of San Luis Obispo and Santa Cruz counties, California, and those of Kentucky are sandstones thororoughly impregnated with bitumen. They are used in their native condition, no substance being added to them. They are prepared for use by crushing to powder which is heated to a temperature of about 250 degrees Fahr., bringing it to a plastic mass; while hot it is spread upon the foundation, tamped and rolled.

96. Analysis of the bituminous sandstones of Ventura County, California, gave the following results:

Bitumen	24 per cent
Silica	64 "
Oxide of iron } Calcium carbonate }	12 "
	100 "

97. Composition of American Rock Asphaltums.—The retort assays of representative specimens of California rock asphaltum gave the results shown in Table XVI.

TABLE XVI.

ASSAYS OF AMERICAN BITUMINOUS ROCKS.

Locality.	Volatile Matter.	Carbon.	Ash (Gravel, Debris, etc.)
	per cent.	per cent.	per cent.
Upper Ojai Rancho Viejo, Cal.	35.8	28.2	36.0
Seesaw Cañon terraces, Cal.	39.0	21.0	40.0
Brea Rancho, Los Angeles Co., Cal.			
" Purest natural	71.4	14.4	14.2
" Rock	29.6	18.4	52.0
" Hard surface	40.1	23.0	36.9
" Refined	41.5	16.9	41.6
Las Breitas, Cal.—Oil-bearing sand.	13.3	.5	86.2 (sand)
Galetas Bed, Cal.—Lower portion	23.1	6.0	70.9 (")
" Pile on wharf	32.8	10.4	56.8 (")
" Purest Veinlet	40.2	11.7	48.1 (")

98. Asphaltum.—Bitumen or mineral pitch (derived from the Greek word *Asphaltos*, to slip) is considered to be a product of the decomposition of vegetable and mineral substances. It was used as a building cement by the ancients, who obtained it from the surface and shores of the Dead Sea (hence called the *Lacus Asphaltites* or asphalt lake). It is usually found of a black or brownish-black color, externally not unlike coal, but it varies in consistency from a bright pitchy condition with a sharp conchoidal fracture to thick viscid masses of mineral tar; it melts a little below the boiling point of water, and it burns with a rather smoky flame.

It is regarded as the ultimate result of a series of changes which take place under certain conditions, in organized matter, producing (1) naphtha, (2) petroleum, (3) mineral tar, and (4) asphaltum

or hard bitumen. The whole of these substances merge into each other by insensible degrees, so that it is impossible to say at what point mineral tar ends and asphaltum begins.

The asphaltums of various localities differ from each other considerably in chemical composition. They all agree, however, in being amorphous, and in having the lustre and general appearance of pitch, whence the name *mineral pitch.*

Deposits of asphaltum exist widely diffused throughout the world, more especially in tropical and subtropical regions. It is found in a state of great purity in the interstices of the older rocks, but its occurrence is not characteristic of any particular formation or period.

The most remarkable deposit of native bitumen exists in the island of Trinidad, W. I., where it forms a lake of upwards of 100 acres in extent and of unknown depth. In addition to the lake, deposits of bitumen occur in the surrounding country.

A considerable quantity of fine bitumen is also obtained from Cuba and Mexico under the names "La Brea" and "Chapapoti," and also from Caxatambo, Peru. The asphaltum of the Dead Sea is more a tradition than a reality, it being now found there in very small quantities; but the source of supply of ancient Babylon, the fountain of Is, on a tributary of the Euphrates, still yields asphaltum.

In many localities asphaltum is found disseminated through the limestone and sandstone rocks, whence the names *bituminous limestones, bituminous sandstones, rock asphaltum, asphalt,* etc.

99. Composition of Asphaltum.—Pure asphaltum, or bitumen, is composed of carbon, hydrogen, and oxygen in the proportion of about carbon 85, hydrogen 12, and oxygen 3. The color is of a deep black, with a very slight tinge of redness; it has a peculiar aromatic odor, which is very strong when at a boiling temperature, but at ordinary temperatures it is scarcely perceptible. At a temperature under 50 degrees Fahr. it is solid and brittle; from 50 degrees to about 70 degrees it is soft and plastic; from 70 degrees to 90 degrees it has a pasty consistence; from 90 degrees to 110 or 120 degrees it is glutinous, and above 120 Fahr. it is liquid. The specific gravity is about 1.03.

Pure asphaltum cannot be used for paving purposes without some admixture of silicious material, on account of its brittleness

at low temperatures, its tendency to soften at high temperatures, and its inability to resist wear and tear.

100. Artificial Asphalts are produced by mixing natural bitumen with crude petroleum, in the proportion of about 100 parts of bitumen to 5 or 20 parts of petroleum. This mixture is what is known as "asphalt cement;" of this 12 or 15 parts are mixed while hot with 83 to 60 parts of sand and from 5 to 30 parts of powdered carbonate of lime. This is the material chiefly employed for asphalt pavements in America.

101. Trinidad Asphaltum.—The island of Trinidad has been the main source of supply for the asphaltum used in street-paving in the United States. This is a natural bitumen mixed with vegetable and earthy matter. It is liquefied by heating over a slow fire. By this process the foreign substances are eliminated, the vegetable impurities rise to the top and are skimmed off, while the earthy constituents settle to the bottom. For street-paving the purified asphaltum is mixed with the residuum of petroleum and sand. The mixing is made at a temperature of about 300 degrees Fahr., and while still hot and plastic it is spread upon the foundation and compressed with heavy rollers.

102. A recent analysis of crude Trinidad bitumen gave the following average results:

Water	25.18 to 26.16 per cent
Bitumen	51.65 "
Non-bituminous matter	10.89 "
Mineral matter	37.46 "

The mineral matter seems to be fine sand with a little clay.

103. Properties of Trinidad Asphaltum.—The crude asphaltum has the following properties: specific gravity, 1.28; hardness at 70 degrees Fahr., 2.5 to 3 in Dana's scale; color, chocolate-brown. The refined asphaltum has the following properties: specific gravity, 1.49; hardness at 70 degrees Fahr., 2.5; color, black. It breaks with a conchoidal fracture, burns with a yellowish-white flame, and in burning emits an empyreumatic odor. One analysis gave

	Per Cent.
Bitumen	59.86
Earthy matter	35.82
Vegetable matter	4.32
	100.00

And on ultimate analysis of the pure bitumen dissolved out by CS^2 there resulted

	Per Cent.
Carbon (C)	85.89
Hydrogen (H)	11.06
Sulphur (S)	2.49
Unknown (possibly oxygen)	0.56
	100.00

After treatment with petroleum residuum in order to make the paving cement, the bitumen soluble in CS^2 varies from 68.5 to 70 per cent.

An analysis of the non-bituminous residue from the last-drawn portion of a tank of cement consisted of

		Per Cent.
Organic matter		7.80
Silica and silicates insoluble in acid		87.67
Containing silica	81.64	
Alumina and trace of iron	7.53	
Alumina		2.20
Iron		1.77
Lime		.50
		99.94

104. Comparative Prices.—The following tables show the ruling prices for the different varieties of asphaltum, the production of bituminous rock and the imports of asphalt in the United States during the year 1889:

TABLE XVII.

PRICES OF ASPHALTUM IN 1889.

	Per Ton.
Trinidad, crude, at New York	$13.00
" refined " " "	30.00
Hard Cuban at New York	28.00
Gilsonite at the mines	60.00
Bituminous rock, California, at the mines	$2.50 to 10.00
" " Kentucky, at the mines	2.40

TABLE XVIII.

PRODUCTION OF BITUMINOUS ROCK IN THE UNITED STATES IN 1889.

California (bituminous rock)	47,968 tons
Kentucky " "	112 "
Utah " "	3,163 "
Utah (gilsonite)	492 "
Total	51,735 "

TABLE XIX.

IMPORTS OF ASPHALTUM TO THE UNITED STATES IN 1890.

Trinidad	54,692 tons
Neufchâtel and Seyssel	200 "
Hanover and Germany	150 "
Sicily	1,500 "
Total	56,542 "

105. Percentage of the Uses for Asphaltum.—In the United States all of the European material is employed in laying sidewalks, and, for interior work, of the Trinidad asphaltum 72 per cent is employed for laying sheet pavement and 24 per cent for manufacturing paving-blocks.

106. Paving-pitch—Gas-tar.—This is the product resulting from the distillations of bituminous coal in the manufacture of gas. It resembles natural bitumen so closely in outward appearance that it was thought at one time to be equally valuable for paving purposes, but many attempts made to employ it instead of asphaltum have resulted in failure. It is now employed for filling the joints in block pavements.

107. Brick—Clay.—Pure clay consists of a hydrated silicate of alumina in combination more or less with other substances derived from the felspathic rocks, which by their disintegration and decomposition have formed the clay. The chemical formula of the most prominent varieties of clay according to Brogniart and others may be expressed by $2Al_2O_3 3SiO_2 4HO$.

108. Pure clay is soft, more or less unctuous to the touch, white and opaque, and when breathed upon emits a characteristic odor. It is infusible, and insoluble either by water, nitric or hydrochloric acids. It may be converted by water into a doughy, tenacious, plastic paste. It absorbs water with avidity, but when burned at a sufficiently high temperature it becomes hard and gritty and loses almost wholly or altogether this property of combining with water. When slowly dried and exposed to red heat, the particles of clay are augmented in volume and possess less density. At the same time, however, the interstitial spaces are diminished and they approach more closely together, giving an increase of density to the whole mass of burnt clay, which is practically observed by a diminution of surface and technically called

the shrinking of the clay. This shrinkage is very materially modified and affected by the admixture and proportion of foreign matters possessing other properties.

109. In nature the greater number of clays is found intermingled with other substances foreign to them in their original localities. The usual constituents of clay are alumina, silica, iron, lime, magnesia, and alkalies, all of which modify the character of the clay and its applications, according as one or other of these ingredients predominates.

110. The ingredients which most affect the character of the clay are the silica, iron, and lime, and its plasticity diminishes in proportion to the amount of any one of these substances which it contains, as they are not plastic. Sand exercises the most marked effect; it possesses no binding properties, and alone it is infusible except at the highest temperatures of the oxyhydrogen blowpipe. Bricks made of clay containing an excess of sand are rough and weak. Iron renders clay fusible, and its presence is objectionable in brick intended for furnace-lining; but in paving-brick it is advantageous, making the brick more homogeneous. Lime, although infusible, is at high temperatures changed into caustic lime, renders the clay fusible, and when exposed to the action of the weather absorbs moisture and causes disintegration. Its presence is to be avoided in clay used for the manufacture of paving-brick. Magnesia exerts but little influence on the character of the clay; in small quantities it renders the clay fusible; at 60 degrees Fahr. its crystals lose their water of crystallization and cold water decomposes them, forming an insoluble hydrate in the form of a white powder. In air-dried brick this action causes them to crack. The alkalies are found in small quantities in the best of clays; from 1 to 3 per cent renders the clay fusible. The greater the amount of quartz and silica that enters into the composition of the clay, the more difficult it will be of fusion.

111. Clay, to make a good paving-brick, must be rich in silica, free from lime, and able to withstand without fusing a red heat for a sufficient length of time to render the bricks hard, homogeneous, and impervious to water.

112. Common hard-burned brick is not suitable for paving purposes, although such brick makes a smooth pavement under light traffic and lasts for a number of years; still, under the influence of

moisture and frost, disintegration is inevitable in the end. Nor will such brick sustain constant heavy traffic, aside from climatic influences. Brick made of suitable clay, however, will stand the severest frosts, and crushing tests show it to be equal to many granites.

113. The color of clay is of no practical importance; it is due to the presence of metallic oxides and organic substances. Clay containing iron produces bricks which are either red, yellow, or blue, according to the quantity of the oxide present and the degree of heat to which they have been subjected; some organic substances produce a blue, bluish-gray, or black color.

114. The manufacture of paving-brick may be classified under six heads:

(1) *Excavation of the clay,* either by hand or steam-power.

(2) *Preparation of the clay* consists in (*a*) removing gravel, stones, or other mechanical impurities; (*b*) grinding the clay. This is performed in either dry or wet pans, and is important: the finer the clay is ground the more homogeneous the brick.

(3) *Tempering.* This is performed in a variety of ways, either with or without the aid of machinery; where the amount of clay to be handled is large, "pug-mills" driven by steam-power are employed.

(4) *Moulding.* The clay is moulded either by hand or machines; hand-moulded brick are generally pressed, but machine-moulded ones do not require it. In moulding paving-brick the utmost amount of clay should be compressed into the mould.

(5) *Drying.* The moulded bricks are slowly dried either in covered sheds open to the air, or in chambers heated for the purpose.

(6) *Burning.* After being sufficiently dried the bricks are piled in kilns, and the firing is conducted with the utmost care, as upon it the perfection of the brick largely depends. The time required for burning is six or more days. The kilns used are of various kinds, some makers preferring up-draft and some down-draft; the size depends upon the extent of the business carried on.

115. A variety of methods is practised in the execution of the above-described operations, and a description of them would be confusing. From the variety and differences of clay, the experience gained in one locality is often of little use in another.

116. Analyses of Clay.—Table XX shows the composition of some of the clays used in the manufacture of paving-brick.

TABLE XX.

ANALYSES OF CLAYS.

Locality.	Silica.	Alumina.	Iron.	Lime.	Magnesia.	Potash.	Soda.	Sulphur.	Chlorides.	Water combined.	Water Hygrometric.	Titanic Acid.	Phosphoric Acid.	Silica Quartz.
Woodbridge, N. J.	42.23	39.53	0.5	0.1	....	0.41	0.08	....	......	13.59	1.21	1.40	....	0.50
" "	42.05	35.83	0.77	....	0.11	0.44	...	....	......	12.20	1.50	1.10	....	5.70
Phillipsburg, "	56.78	17.38	6.50	4.14	3.15	3	.42	0.89	.....	7	.60	......	0.13	....
Winchester, Ill....	23.15	17.08	3.47	....	0.28	1.10	....	....	......	6.30	1.20	0.90	....	46.70
Bloomington, Ill..	67.80	11.55	4.31	8.90	5.32	2	.42	....	trace	0	.20	trace	....	....
Cheltenham, Mo..	61.22	25.64	1.70	....	....	1	.31	0.4	......	9.68	.....	......	....	.....
" "	38.10	31.53	2.32	....	tr.	0.40	....	....	......	11.30	2.50	1.50	....	12.70
Montgomery, Mo..	43.93	40.09	0.88	....	...	0.20	....	....	......	13.80	0.80	tr.*	....	0.60
Woodlawn, Penn..	42.15	31.43	1.57	....	0.32	2.01	....	....	......	9.40	1.20	1.00	....	10.25
Mt. Savage, Md...	39.90	30.08	1.67	...	....	2.30	...	....	......	7.00	6.90	1.15	....	16.90
Carter Co., Ky....	46.75	38.17	0.29	0.57	0.12	0	.07	....	......	14	.03	......	....	.....
Marion Co., W. Va.	59.25	32.26	....	7.16	...	....	....	....	......	1	.83	......	....	.....
San Fran., Cal....	56.51	21.33	12.31	3.53	tr.	...	....	....	......	6.30	.....	......	...	.....
Haydensville, O...	72.24	16.87	0.16	0.50	tr.	1	.09	....	......	5.14	.....	......	....	.....
Burlington, Ia ...	77.40	11.74	3.29	1.60	1.91	3.76	0.47	....	......	.....	.....	......	....	.....
Clinton, " ...	73.82	15.88	2.92	tr.	tr.	4.5	....	....	......	3.0	.....	......	....	.....
Morrison, Colo....	71.8	15.0	tr.	3.8	....	....	. .	....	......	8.3	.....	......	....	.....
Golden, "	52.41	32.21	0.66	0.20	0.61	0.61	....	....	......	14.05	.....	......	....	.....
Stourbridge, Eng.	67.34	23.03	2.03	....	....	1	.38	....	......	8.24	.....	......	....	.....
" " .	64.05	23.15	1.85	....	....	0	.10	....	......	10.00	.....	......	....	.....

* With Al_2O_3.

117. The Characteristics of Brick suitable for Paving are:

(1) Not to be acted upon by acids.

(2) Not to absorb more than $\frac{1}{800}$ of its weight of water in 48 hours.

(3) Not susceptible to polish.

(4) Rough to the touch, resembling fine sandpaper.

(5) To give a clear ringing sound when struck together.

(6) When broken to show a compact, uniform, close-grained structure, free from air-holes and pebbles.

(7) Not to scale, spall, or chip when quickly struck on the edges.

(8) Hard but not brittle.

118. Tests of Brick.—The following is the schedule of tests to which the paving-brick used in Washington, D.C., are subjected. (G. J. Fiebeger, Capt. of Engineers, U. S. A.)

(1) Carefully measure.

(2) Dry for 48 hours.

(3) Weigh.

(4) Immerse in water for 48 hours (break some of the samples before immersing).

(5) Weigh for percentage of absorption.

(6) Dry.

(7) Grind two bricks of each class for eight hours (this was done on a horizontal stone 14 feet in diameter, making 28 revolutions a minute; the bricks were put in a cradle and carefully watched so that each should be subjected to the same test).

(8) Dry.

(9) Weigh to determine percentage of loss.

(10) Two bricks of each class put in a rumbler for half an hour, this rumbler making 28 revolutions per minute.

(11) Weigh to determine percentage of loss.

(12) Relative general appearance, determined by considering character and appearance as a paver. Study of fracture and structure of sample.

(13) Determine weight per cubic inch.

Add together the numbers indicating order in each test. The sample having the lowest total will be considered as having passed the test most satisfactorily, unless fatally defective in any one test. After determining the relative quality, the size and price of the best specimens will be considered. Table XXI shows the results of tests carried out in the above manner on several varieties of brick.

119. Specific Gravity, Weight, Resistance to Crushing, and Absorptive Power of Paving-brick. In regard to these qualities the paving-bricks made by different manufacturers and by the same manufacturer vary considerably, as will be seen from Table XXI. In weight they vary from 5 to $7\frac{1}{2}$ pounds; in specific gravity, from 1.91 to 2.70; in resistance to crushing, from 7000 to 18,000 pounds per square inch; in absorption, from 0.15 to 0.60 per cent.

120. Wood.—Both the hard and soft varieties of wood have been employed for paving. In the United States, cedar and cypress, on account of their abundance and cheapness, are more generally used. Recently mesquite, which grows in abundance in both Texas and Mexico, has been used. In Europe nearly all varieties of the

TABLE XXI.

TESTS OF PAVING-BRICKS AT WASHINGTON, D. C.

(By G. J. FIEBEGER, Captain of Engineers, U. S. A.)

Number of Proposal.	Av. Weight. Lbs., oz.	Absorption. Per Cent.	Tumbling ½ Hr. Per Cent Loss.	Grinding 8 Hrs. Per Cent Loss.	Density. Wt. Cu. In. Oz.	Uniformity of Structure. Order of Merit.	Price per M.	Grade.
1	$6.15\frac{7}{12}$	.029	.040	.131	1.286	5	$18 50	Ordinary
2	$6.14\frac{4}{12}$	.015	.075	.102	1.307	8	21.00	Re-pressed
3	$5.11\frac{9}{12}$	.043	.084	.227	1.215	9	21.00	Re-pressed
4	6.13	.025	.065	.167	1.201	4	19.00	Ordinary
5	$6.8\frac{10}{12}$	.060	.090	.364	1.198	12	17.93	Re-pressed
6	$6.2\frac{10}{12}$	.047	.036	.231	1.141	11	18.50	Ordinary
7	$6.10\frac{6}{12}$	.042	.060	.194	1.154	6	17.72	Ordinary
8	$5.14\frac{8}{12}$	.052	.050	.170	1.196	10	18.38	Ordinary
9	$6.9\frac{5}{12}$	.036	.023	.132	1.206	2	18.00	Ordinary
10	$6.12\frac{3}{12}$	.033	.018	.112	1.274	1	19.00	Re-pressed*
11	$6.8\frac{10}{12}$	.018	.070	.159	1.197	3	19.75	Ordinary
12	$7.3\frac{5}{12}$	.019	.123	.138	1.178	7	19.75	Ordinary

* Contract awarded.

In size the bricks varied from 8[illegible] to 8[illegible] inches in length, from $3\frac{27}{32}$ to $4\frac{11}{32}$ inches in width, and from 2[illegible] to $2\frac{23}{32}$ inches in thickness.

pine species have been tried, as well as oak, ash, and elm, but Memel and Dantzic fir appears to be the favorite.

121. Whichever kind is used, it should be sound, close-grained, uniform in quality, free from knots and sap and from the blue tinge which is a sign of incipient decay. All sappy wood should be rejected.

122. The use of creosote or other preserving processes makes it difficult to discover defects in the wood, and on this account is objectionable. It is doubtful if creosoting, etc., adds to the life of wood employed for paving.

123. Sand.—Sand is an aggregation of loose incoherent grains crystalline in structure and angular in shape, of silicious, argillaceous, calcareous, or other material, derived from the disintegration of rocks or other mineral matter, and unmixed with earth or organic matter. For road purposes the grains should not exceed one eighth of an inch in size.

124. The principal use of sand is as a foundation for broken stone, a cushion and bed for stone paving-blocks, and as a joint fill-

TABLE XXII.

SPECIFIC GRAVITY, WEIGHT, AND RESISTANCE TO CRUSHING OF VARIOUS WOODS.

	Specific Gravity.	Average Weight, pounds per cubic foot.	Resistance to Crushing, pounds per square inch.
Acacia	.71 to .79	44	16,000
Ash, American white, dry	.61	38	8,900
Beech	.69	43	7,700
Cedar, American white	.36	22.45	4,400
Chestnut, "	.46	22.80	5,300
Chestnut	.60	38	.....
Cypress, American	.408	24.4	6,000
Deal, Christiania	.689	43	5,850
Ebony	1.187	74	19,000
Elm	.56	35	.....
Fir, American (Pacific region)	.405	25.28	.....
Fir, European	.512	32	6,500
Hemlock, Am. (Atlantic region)	.409	25.5	5,300
Hickory	.85	53	.....
Lignum vitæ	1.33	83	10,000
Mahogany, Spanish	.85	53	8,200
" Honduras	.56	35	8,000
Maple	.79	49	.....
Mesquite, American (Texas)	.756	47	10,450
Oak " white (Atlantic)	.763	46.5	7,000
" " chestnut "	.711	44	7,500
" " red "	.751	46.7	7,000
" " black "	.687	43.8	7,000
" English	.777	48	6,400
" "	.934	58	10,000
Pine, American white	.35 to .45	21 to 25	5,400
" " red	.485	30	6,800
" " yellow (Pacific)	.530	33	12,000
" " pitch (Atlantic)	.632	39	5,000
" Dantzic	.649	40	5,400
Redwood, American (California)	.473	29.5	9,500
Spruce, " (Atlantic)	.408	25.4	5,700

ing. For these purposes it is eminently suitable, because when confined so that it cannot escape or spread it possesses the valuable properties of incompressibility, and mobility or the quality of assuming a new position when any portion of it is disturbed.

As a base or cushion for blocks it quickly adjusts itself to every irregularity of their inferior surfaces, and when the blocks finally settle in place it furnishes a solid incompressible medium to transfer the pressure to the foundation below. For this purpose it should be fine and dry; if coarse and damp, the blocks will adjust them-

TABLE XXIII.

ABSORPTIVE POWER OF WOOD.

(E. R. ANDREWS in "Engineering News.")

	Percentage of Water absorbed.	
	Dry Wood.	Creosoted.
Black gum	1.0000	.1250
Cottonwood	.7140	.3470
Oak	.2000	.0625
Spruce	.1754 to .3333	.0236 to .0306
" (Burnettized .2500)		
Hard pine	.1600	.0000
White birch	.4300	.1240
Sesquoia gigantea (tree of California)	.4722	.0000

selves with difficulty and the fewer will be the points of support between them and the foundation, and the greater will be the pressure of contact and liability to unequal settlement.

125. Sharp sand, i.e., sand with angular grains, is much better than that with rounded grains, although it is often difficult to obtain. The sharpness of sand can be determined approximately by rubbing a few grains in the hand or by crushing it near the ear and noting if a grating sound is produced.

126. The sand for bedding blocks and jointing should be clean, i.e., free from loam or clay. The cleanness may be tested by rubbing a little of the dry sand in the palm of the hand and, after throwing it out, noticing the amount of dust left on the hand. The cleanness of sand may also be judged by pressing it together between the fingers while it is damp; if the sand is clean, it will not stick together, but immediately fall apart when the pressure is removed.

127. For concrete used for foundation it is not necessary that the sand should be free from clay; indeed a small amount of clay may be beneficial. Clay when dissolved or finely pulverized consists of an almost impalpable powder, and when mixed with sand its particles occupy the interstices between the particles of cement and sand, and are also completely enveloped by the cementing paste. Clay, dissolved or finely pulverized, mixed with cement up to the

proportion of 1 to 1, appears to affect the strength essentially the same as an equal quantity of sand, and the mortar is much more dense, plastic, and water-tight. Such mortar is not affected by the presence of water.

The voids of ordinary sand average from 0.3 to 0.5 of the volume; the more uneven the sizes the smaller the voids.

128. The quantity of sand required for bedding paving-blocks is about one cubic yard to six square yards of paving.

129. The price of sand varies from 40 cents to $1.60 per yard, according to locality.

130. Sand is sometimes sold by the ton. It weighs when dry from 80 to 115 pounds per cubic foot, or about 1 to 1½ tons per cubic yard.

131. Gravel is an accumulation of small stones which vary in size from a small pea to a walnut or something larger. It is often intermixed with other substances, such as sand, clay, loam, etc., from each of which it derives a distinctive name. In selecting gravel for road purposes the chief quality to be sought for is the property of binding (see Art. 421).

"The so-called Tomkins Cove gravel, which is much used about New York, is a broken limestone, apparently of the cement series. It is usually spread over the road, and compacted by the traffic. The darker-colored stone is very pleasant to the eye, and it readily makes a smooth wheelway singularly free from either mud or dust even when subjected to rather heavy traffic, though it is too friable for economical use in such situations. Its performance is so different from that of the ordinary limestones that an analysis is appended:

Lime	60.20	per cent
Alumina	11.22	"
Silica	6.18	"
Magnesia	10.45	"
Carbonic acid	8.00	"
Water	4.00	"
	100.00	per cent

132. Shingle is the gravel or accumulation of small stones found on the shores of rivers or the sea.

TABLE XXIV.

SPECIFIC GRAVITY, WEIGHT, AND RESISTANCE TO CRUSHING OF VARIOUS SUBSTANCES.

Substance.	Specific Gravity.	Weight, pounds per cubic foot.	Resistance to Crushing, lbs. per sq. in.
Asphaltum .905 to 1.65	1.277	80 to 87.3	....
Basalt (greenstone)	2.9	181	17,200
" Scotch	2.95	184	8,300
Bitumen, liquid	.848	53	....
Bituminous limestones	2.25	156	....
Brick, best pressed	2.4	150	14,973
" common hard	1.6 to 2	125	12,000
" soft inferior	1.4	100	600 to 3,000
" Stourbridge fire	2.2	137	1,717
" paving	....	....	9,000 to 15,000
" work in cement-mortar masonry	1.8	112.5	....
Chalk	2.5	156	501
Clay	1.8 to 2.1	119	....
" dry, in lumps loose	....	63	....
" with gravel	2.48	155	....
Cement, hydraulic American Rosendale	....	56.60	....
" English Portland	1.6 to 1.76	81 to 102	....
" French "	....	76 to 88	....
" Roman	1.6	100	....
Concrete, ordinary	1.9	119	....
" cement (Portland)	2.2	137	....
Earth, common loam, dry, loose	1.28 to 2	72 to 80	....
" common loam perfectly dry, shaken	....	82 " 92	....
Earth, common loam, perfectly dry, moderately rammed	....	90 " 100	....
Earth, common loam, slightly moist, loose	....	70 " 76	....
" " " more moist loose	....	66 " 68	....
" " " " " shaken	....	75 " 90	....
" " " " " mod. packed	....	90 " 100	....
" " " as a soft flowing mud	....	104 " 112	....
Earth, common loam as a soft flowing mud well pressed into a box	....	110 " 120	....
Flint	2.6	126	....
Feldspar	2.5 to 2.8	166	....
Glass	2.5 to 3.45	186	27,000–30,000
Gneiss	2.69	168	....
" in loose piles	....	96	....
" hornblendic	2.8	175	....
" quarried in loose piles	....	100	....
Gun-powder, loose	.900	56.25	....
" shaken	1.000	62.5	....
Iron, cast	7.21	450	110,000
" wrought	7.69	485	45,000
Ice	.917 to .922	57.4	....
Lead	11.30 to 11.47	709.6	6,944–7,730
Lime, quick, of ordinary limestones	1.5	95	....
" quick, ground, loose	....	53	....
" " well shaken	....	64	....
" " thoroughly shaken	....	75	....
Masonry of granite or limestone dressed	....	165	....
" of rubble, $\frac{1}{3}$ of the mass being mortar	....	154	....
" of dry rubble	....	138	....
" of sandstone dressed	....	144	....
" of brickwork, close joints	....	140	....
" " " medium quality	....	125	....
" " " soft bricks	....	100	....
Mica	2.75 to 3.1	183	....
Mortar	1.38 to 1.9	106	....
Mud, dry, close	....	80 to 110	....
" wet, moderately pressed	1.63	110 " 130	....
" wet, fluid	....	104 " 120	....
Naphtha	.848	52.9	....

TABLE XXIV.—*Continued.*

SPECIFIC GRAVITY, WEIGHT, AND RESISTANCE TO CRUSHING OF VARIOUS SUBSTANCES.

Substance.	Specific Gravity.	Weight, pounds per cubic foot.	Resistance to Crushing, lbs. per sq. in.
Petroleum	.878	54.8	
Peat, dry, unpressed		20 to 30	
Pitch	1.15	69	
Porphyry	2.66 to 2.8	170	
Quartz, pure	2.65	165	
" finely pulverized, loose		90	
" " " shaken		105	
" " " packed		112	
" quarried, loose		94	
Sand of pure quartz, dry and loose	2.75	90 to 106	
" " " " perfectly wet		118 " 129	
" river	1.88	117	
" pit, coarse	1.61	100	
" " fine	1.52	95	
" (Thames) England	1.64	102	
Serpentines	2.5 to 2.6	162	
Shales, red or black	2.6	162	
" quarried in piles		92	
Shingle	1.42	88	
Slate	2.7 to 2.9	175	10,000–21,00[illegible]
Soapstone or steatite	1.73	170	
Steel	7.85	490	336,000
Snow, freshly fallen		5 to 12	
" compacted		15 " 20	
Water, pure rain, or distilled at 32° Fah., barom. 30 inches		62.417	
Water, pure rain, or distilled at 62° Fah., barom. 30 inches	1.00	62.355	
Water, pure rain, or distilled at 212° Fah., barom. 30 inches		59.7	
Water, sea 1.026 to 1.030	1.028	64.08	

CHAPTER III.

STONE PAVEMENTS.

133. Stone Pavements.—Stone in a variety of forms has been employed as a paving material for more than 2500 years. The Romans used it in the form of large, irregularly-shaped blocks laid on a massive foundation of concrete. In this form it is unsurpassed in regard to solidity and durability, but it is objectionable for modern traffic. The surface of the large blocks wears smooth, and hence affords but an uncertain foothold for horses. These large blocks were superseded by round pebbles or cobblestones, obtained from the beach and gravel-pits. This class of pavement has been used extensively in the United States. It is recorded that Boston, Mass., in 1663 had many streets paved with pebbles. In 1718 cobblestone pavements were introduced into Philadelphia, and this city is the only one to retain them on a large scale at the present day.

134. Cobblestone Pavement.—Cobblestones bedded in sand possess the merit of cheapness and afford an excellent foothold for horses, but the roughness of such pavements requires the expenditure of a large amount of tractive energy to move a load over them. Aside from this, cobblestones are entirely wanting in the essential requisites of a good pavement. The stones being of irregular size, it is almost impossible to form a bond or hold them in place. Under the action of the traffic and frost the roadway soon becomes a mass of loose stones. Moreover, cobblestone pavements are difficult to keep clean, and very unpleasant to travel over.

135. Specifications for Cobblestone Pavement.—The following is the common form of specification for this class of pavement:

Stone.—The stones are to be the best selected water or bank paving-stones, of a durable and uniform quality.

TYPES OF STONE PAVEMENTS.

Fig 1 ROMAN.

Fig 2. COBBLE STONE.

Fig 3. BELGIAN BLOCK.

FIG. 4. EARLY GRANITE BLOCK.

Size of Stone.—No stone shall be less than four (4) inches nor more than eight (8) inches in any direction on the surface. No triangular or split stone will be allowed. All stones shall be set perpendicular and on their small ends, the large stones to be placed on the sides of the street, and the small ones in the center.

Foundation and Laying.—The pavement shall be laid on a bed of good sharp sand or fine gravel, at least ten (10) inches in depth, except where clay or a similar substance is met with, when the sand must be eighteen (18) inches deep. The bed of sand or gravel shall be laid ready for the pavement at least thirty (30) feet in advance of the pavement. The stones after being set in position must be rammed with a heavy rammer until they are firmly settled in their beds. After the pavement is rammed a layer of sand or gravel two (2) inches thick is spread over it and left to work its way in between the stones.

In consequence of the many defects of this class of paving its construction has been practically abandoned, but large areas still remain, which are being gradually removed.

136. Belgian Block Pavement.—Cobblestones were displaced by pavements formed of small cubical blocks of stone. This type of pavement was first laid in Brussels, thence imported to Paris, and from there to the United States, where it has been widely known as the "Belgian block" pavement. It has been largely used in New York City, Brooklyn, and neighboring towns, the material being trap-rock obtained from the Palisades on the Hudson River.

137. The stones being of regular shape remain in place better than the cobblestones, but the cubical form (usually five inches) is a mistake. The foothold is bad, the stones wear round, and the number of joints is so great that ruts and hollows are quickly formed. This pavement offers less resistance to traction than cobblestones, but it is rough and noisy.

138. Specification for Belgian Block Pavement.—The following is the common form of specifications for the Belgian block:

Stone.—The stones are to be obtained from the trap or other durable rocks.

Size of Stones.—Each block shall measure not less than five (5) inches nor more than seven (7) inches in length; nor less than five (5) inches nor more than six (6) inches in width; in depth not less than six (6) inches nor more than seven (7) inches; nor shall

the difference between the base and the top surface of any block exceed one inch in either direction.

139. The blocks are laid upon a foundation of sand six inches thick, in parallel courses, perpendicular to the axis of the street. When so laid the blocks are thoroughly rammed to the required grade and cross-section. No ramming should be done within twenty-five feet of the work that is being laid. After ramming the surface is covered with a coat of clean sand which is broomed into the joints.

140. Granite Block Pavement.—The Belgian block has been gradually displaced by the introduction of rectangular blocks of granite. Blocks of comparatively large dimensions were at first employed. They were from 6 to 8 inches in width on the surface, by from 10 to 20 inches in length, with a depth of 9 inches. They were merely placed in rows on the subsoil, perfunctorily rammed, the joints filled with sand, and the street thrown open to traffic. The unequal settlement of the blocks, the insufficiency of the foothold, and the difficulty of cleansing them led to the gradual development of the latest type of stone-block pavements, which consists of narrow rectangular blocks of granite, properly proportioned, laid on an unyielding and impervious foundation, with the joints between the blocks filled with an impermeable cement. This type is practically a return to the system of the Romans, but with blocks of lesser dimensions than they used.

141. Experience has proved beyond doubt that this latter type of pavement is the most enduring and economical for roadways subjected to heavy and constant traffic. Its advantages are many, while its defects are few.

142. Advantages.

(1) Adaptability to all grades.

(2) Suits all classes of traffic.

(3) Exceedingly durable.

(4) Foothold, fair.

(5) Requires but little repair.

(6) Yields but little dust or mud.

(7) Facility for cleansing, fair.

143. Defects.—(1) Under certain conditions of the atmosphere its surface becomes greasy and slippery.

(2) The incessant din and clatter occasioned by the movement

IMPROVED GRANITE-BLOCK PAVEMENT.

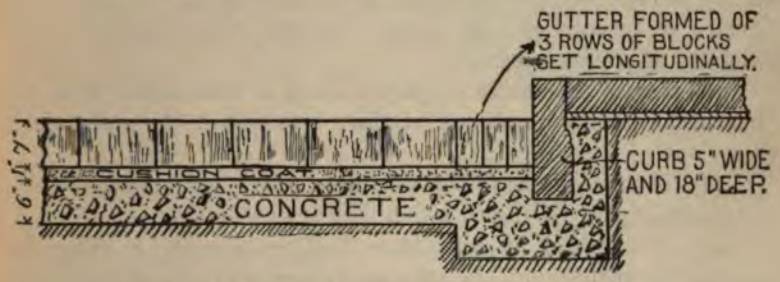


Fig. 5. CROSS SECTION.

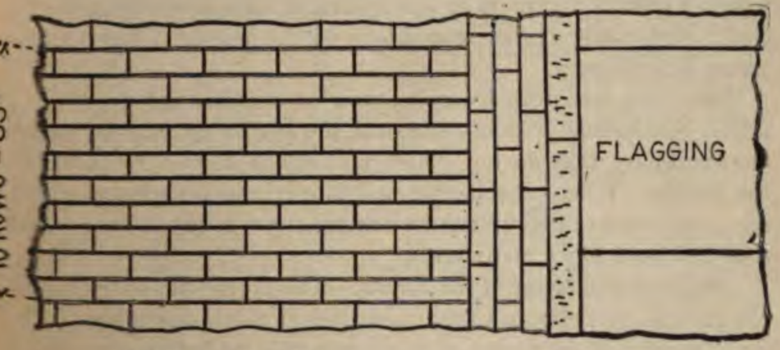


Fig. 6. PLAN.

Fig. 7. LONGITUDINAL SECTION.

of traffic over it is an intolerable nuisance, and it is claimed by many physicians that the noise injuriously affects the nerves and health of persons who are obliged to live or do business in the vicinity of streets so paved.

(3) Horses constantly employed upon it soon suffer from the continual jarring produced in their legs and hoofs, and quickly wear out.

(4) The discomfort to persons riding over it is very great because of the continual jolting to which they are subjected.

(5) If stones of an unsuitable quality are used, i.e., those that polish, the surface quickly becomes slippery and exceedingly unsafe for travel.

144. Quality of the Stone.—The harder and more durable rocks like basalt and true granite are unsuitable; they have the fault of wearing smooth and more or less spherical when subjected to heavy traffic, and under certain conditions of the weather they become greasy and slippery.

145. The less durable rocks, such as syenite, the granites in which hornblende predominates, and the harder sandstones, are the most suitable; they do not polish and afford a good foothold for the horses. Where the harder and more durable rocks have been used, they have caused dissatisfaction, and have been removed before they had been down many years.

146. Size and Shape of the Blocks.—The proper size of the blocks for paving purposes has been a subject of much discussion, and a great variety of forms and dimensions are to be found in all cities.

For stability a certain proportion must exist between the depth, the length, and the breadth. The depth must be such that when the wheel of a loaded vehicle passes over one edge of its upper surface it will not tend to tip up. The resultant direction of the pressure of the load and adjoining blocks should always tend to depress the whole block vertically; where this does not happen the maintenance of a uniform surface is impossible. To fulfil this requirement it is not necessary to make the block more than seven (7) inches deep.

147. Width of the Blocks.—The maximum width of the blocks is controlled by the size of horses' hoofs. To afford good foothold to horses drawing heavy loads, it is necessary that the width of each block measured along the street shall be the least possible consistent with stability; if it is large, a horse drawing a heavy load attempt-

ing to find a joint slips back, and requires an exceptionally wide joint to pull him up. It is therefore desirable that the width of a block should not exceed three (3) inches, or that four taken at random and placed side by side will not measure more than fourteen (14) inches.

148. Length of the Blocks.—The length measured across the street must be sufficient to break joints properly, for two or more joints in a line lead to the formation of grooves. For this purpose the length of the block should be not less than nine (9) inches nor more than twelve (12) inches.

149. Form of the Blocks.—The blocks should be well squared and must not taper in any direction; sides and ends should be free from irregular projections. Blocks that taper from the surface downwards (wedge-shaped) should not be permitted in the work; but if any are allowed, they should be set with the widest side down.

150. Manner of Laying the Blocks.—The blocks should be laid in parallel courses, with their longest side at right angles to the curb. No advantage is gained from a slanting direction, which makes the wear more irregular.

151. The gutters should be formed by three or more courses of block, laid with their length parallel to the curb.

152. At junctions of streets the courses may be laid as shown in Fig. 11, or they may be laid meeting at an angle at the center line of the narrower street as shown in Fig. 11*a*, thereby affording a better foothold for horses turning the corner. The ends of the diagonal blocks where they abut against the straight blocks must be properly cut to the required bevel.

153. The blocks forming each course must be of the same depth, and no deviation greater than one quarter (¼) of an inch should be permitted. The blocks should be assorted as they are delivered, and only those of corresponding depth and width should be used in the same course. The better method would be to accurately gauge the blocks at the quarry: the cost would be considerably less; it would also avoid the inconvenience to the public by the stopping of travel resulting from the rejection of defective material on the ground. This method would undoubtedly be preferable to the contractor, who would be saved the expense of handling unsatisfactory material, and it would also leave the inspectors free to pay more attention to the manner in which the work of paving is performed.

The accurate gauging of the blocks is a matter of much importance. If good work is to be executed, the blocks when laid must be in parallel and even courses; and if the blocks be not accurately gauged to one uniform size, the result will be a badly paved street with the courses running unevenly.

The cost of assorting the blocks into lots of uniform width, after delivery on the street, is far in excess of any additional price which would have to be paid for the accurate gauging at the quarry.

154. Foundation.—The foundation of the blocks must be solid and unyielding, a bed of hydraulic cement concrete is the most suitable, the thickness of which must be regulated according to the traffic; the thickness, however, should not be less than four (4) inches and need not be more than nine (9) inches. A thickness of six (6) inches will sustain at raffic of 600 tons per foot of width.

155. Cushion-coat.—Between the surface of the concrete and the base of the blocks there must be placed a cushion-coat formed of an incompressible but mobile material, the particles of which will readily adjust themselves to the irregularities of the base of the blocks and transfer the pressure of the traffic uniformly to the concrete below. A layer of dry, clean sand ¾ of an inch thick forms an excellent cushion-coat. Its particles must be of such fineness as will pass through a No. 8 screen; if coarse and containing pebbles, they will not adapt themselves to the irregularities of the base of the blocks, hence the blocks will be supported only at a few points and unequal settlement will take place when the pavement is subjected to the action of traffic. The sand must also be perfectly free from moisture, artificial heat must be used to dry it if necessary. This requirement is an absolute necessity. There should be no moisture below the blocks when laid, nor should water be allowed to penetrate below the blocks; if such happens, the effect of frost will be to upheave the pavement and crack the concrete.

Where the best is desired without regard to cost, a layer half an inch thick of asphaltic cement may be substituted for the sand with superior and very satisfactory results.

156. Laying the Blocks.—The blocks should be laid stone to stone, so that the joint may be of the least possible width; wide joints cause increased wear and noise and do not increase the foothold. The courses should be commenced on each side and worked toward the middle, and the last stone should fit tightly.

157. Ramming.—After the blocks have been set they should be well rammed down, and the stones which sink below the general level should be taken up and replaced with a deeper stone or brought to level by increasing the sand-bedding.

158. The practice of workmen is invariably to use the rammer so as to secure a fair surface. This is not the result intended to be secured, but to bring each block to an unyielding bearing. The result of such a surfacing process is to produce an unsightly and uneven roadway when the pressure of traffic is brought upon it. The rammer used should not weigh less than fifty pounds and have a diameter of not less than three inches.

159. Joint-filling.—All stone-block pavements depend for their water-proof qualities upon the character of the joint-filling. Joints filled with sand and gravel are of course pervious. A grout of lime or cement mortar does not make a permanently water-tight joint; it becomes disintegated under the vibration of the traffic. An impervious joint can only be made by employing a filling made from bituminous or asphaltic material; this renders the pavement more impervious to moisture, makes it less noisy, and adds considerably to its strength.

160. The mode of applying the bituminous cement is nearly similar to that of ordinary grouting: the joints are filled to a depth of about two inches with gravel, then the heated pitch is poured in to a depth of one inch on top of the gravel, then more gravel thrown in, then more pitch, then more gravel added until it reaches to within half an inch of the top of the blocks; this remaining half-inch is filled with pitch, then fine gravel sprinkled over the joints.

161. Bituminous Cement for Joint-filling.—The bituminous cement is composed of coal-tar pitch made from coal-tar, gas-tar, and creosote oil, in the proportion of 100 pounds of pitch to 4 gallons of tar and 1 gallon of creosote. These proportions are varied somewhat, according to the quality of the pitch employed. The mixture is melted and boiled from one to two hours in a suitable boiler, then poured into the joints in a boiling state. This mixture is impervious to moisture and possesses a degree of elasticity sufficient to prevent it from cracking. The quantity required per square yard is from three and one half to four gallons. The cost per gallon is about eight cents.

A joint-filling known as "Murphy's Grout Filling" has been and is extensively used in the Central States. This filling is composed of Portland cement, iron-slag, and sand. It is said to be waterproof, durable, and cheap. It can be used with equal advantage for block, brick, cobblestone, and macadam pavements.

In manner of application it differs but little from that of the bituminous cement. It is mixed in a portable box, and when of a good flowing (but not liquid) consistency it is thrown upon the pavement with shovels and swept into the joints with steel brooms, and after forty-eight hours it is set and the pavement is ready for traffic.

162. Sandstone-block Pavements.—Block pavements formed of Medina and Berea sandstones are used in several of the Lake cities, While not as lasting as granite, the sandstone is very durable, is less noisy, and does not become polished or slippery under traffic, wears evenly, and is adapted to all classes of traffic.

163. The best examples of this kind of pavement are found in Buffalo, N. Y., where two classes are used. For first class the specifications call for a foundation of six inches of concrete with a three-inch cushion of sand. The blocks are of dressed stone, four inches wide, seven inches deep, and not less than eight inches long. The joints are filled with bituminous cement. For the second class the blocks are of irregular size laid on a foundation of ten to eighteen inches of sand, depending upon the character of the subsoil, the joints are filled with sand."

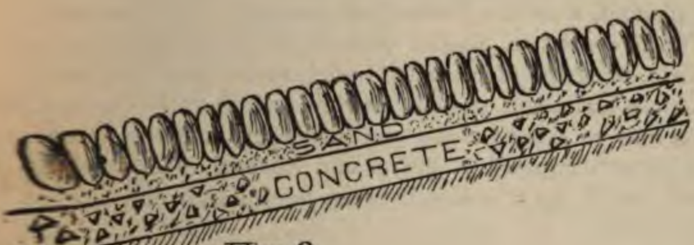
164. The cost of first-class Medina in Buffalo is $4 per square yard; Cleveland, $3.50; Columbus, with a 10-inch broken-stone foundation, $3.25. Second-class average $1.75, and with asphalt filling cost 36 cents per yard more.

165. Limestone-block Pavements.—Limestone block was tried in Kansas City on a concrete foundation, but being set on edge it wore unevenly, and in a year or two was shivered and split by the frost. This is the universal experience of all cities using limestone blocks.

166. Pavements on Steep Grades.—Stone blocks may be employed on all practicable grades, but on grades exceeding 10% cobblestones afford a better foothold than blocks. The cobblestones should be of a uniform length, the length being at least twice the breadth, say stones 6 inches long and 2½ to 3 inches in

diameter. These should be set on a concrete foundation, laid stone to stone, and the interstices filled with cement grout or

STONE PAVEMENTS ON GRADES.



Fig, 8.

Fig, 9.

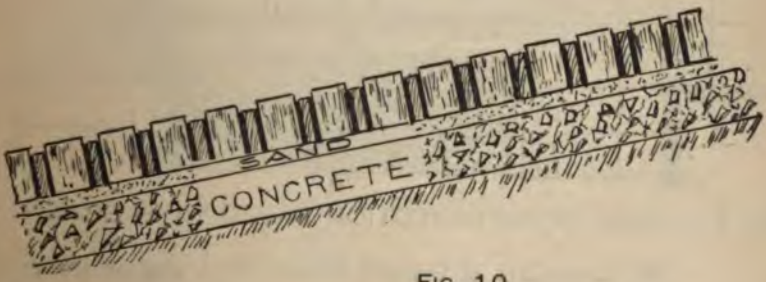


FIG. 10.

bituminous cement; or a bituminous concrete foundation may be employed and the interstices between the stones filled with

asphaltic paving-cement. Should stone blocks be preferred, they must be laid, when the grade exceeds 5%, with a serrated surface by either of the methods shown in Figs. 9 and 10. The method shown in Fig. 9 consists in slightly tilting the blocks on their bed so as to form a series of ledges or steps, against which the horses' feet being planted, a secure foothold is obtained. The method shown in Fig. 10 consist in placing between the rows of stones a course of slate, or strips of creosoted wood, rather less than one inch in thickness and about an inch less in depth than the blocks; or the blocks may be spaced about one inch apart, and the joints filled with a grout composed of gravel and cement. The pebbles of the gravel should vary in size between one quarter and three quarters of an inch.

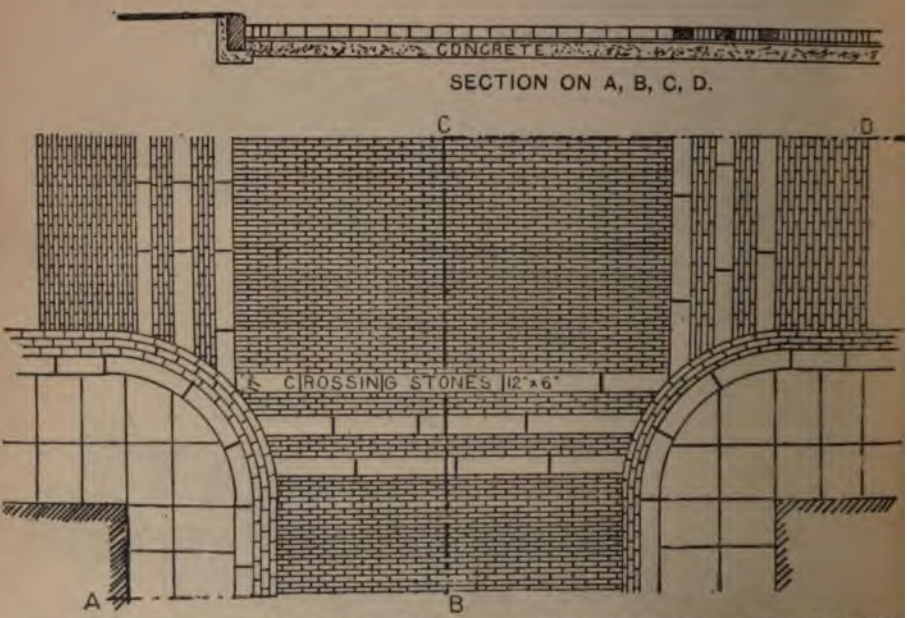


FIG. 11.—PLAN OF INTERSECTION PAVED WITH GRANITE BLOCKS

167. Durability of Granite Blocks.—The average life or durability of granite blocks under heavy traffic may be taken at fifteen years; but since the nature of the traffic, the state of cleanliness and other conditions must be taken into account when inquiring

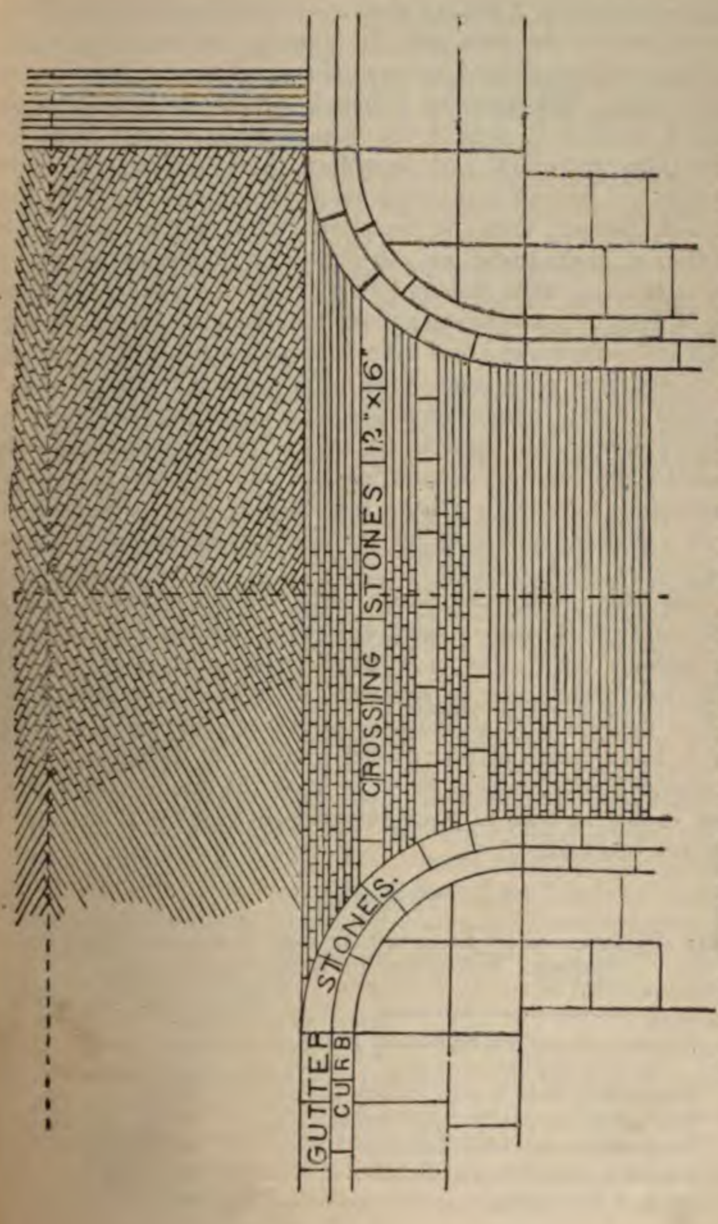


FIG. 11A.—STREET INTERSECTION PAVED WITH GRANITE BLOCKS.

into the durability, it follows that in no two streets is the endurance or the cost the same, and the difference between the highest and the lowest period of endurance and amount of cost is very considerable. The practice followed almost uniformly in the English cities is to remove the worn blocks, re-dress them and relay them in other and secondary thoroughfares. Thus the duration or life of the blocks may be doubled or more than doubled. Indeed, with the exception of the portion worn off by the friction of the traffic, not a fragment of granite paving may be said to be lost. After passing its first years in a leading thoroughfare it goes into a secondary thoroughfare until completely worn down and rounded, and will even then command a price of from 30 to 60 cents per square yard. Not even a fragment that is knocked off the component stones when undergoing the operation of being dressed into shape is lost, as it is made available either for macadamizing or for concrete to form the foundation of other pavements. "In truth granite can only be said to be worn out when it has been broken up for macadamization and then crushed into powder by the vehicles."

168. Wear of Granite Blocks.—Stones from different quarries and even from the same quarry will show considerable variation in the amount worn away in a given time under exactly similar conditions. Therefore no statement of wear can be given which will be applicable to all varieties of stones. On London bridge, which has a traffic of over 15,000 vehicles in 12 hours, the wear of granite blocks has been found to be at the rate of .222 inch per year, or the number of years required to wear away one inch is four and one half.

TABLE XXV.

WEAR AND DURATION OF ABERDEEN GRANITE PAVEMENTS IN THE CITY OF LONDON. BLOCKS 3 INCHES WIDE, 9 INCHES DEEP.

Aberdeen Granite Pavements.	Vertical Wear. Inches.	Duration. Years.
Vertical wear per 100 vehicles in 12 hours, per foot of width per year	$\frac{1}{16}$	1
Total vertical wear in principal streets	2	15
Total additional wear in minor streets	2	20
Total vertical wear when laid aside	4	35
Remaining depth when laid aside	5	
Depth of new blocks	9	

In Liverpool, under a traffic of 216,570 tons per yard of width per annum, the wear was not measurable.

169. Cost of Maintaining Granite-block Pavements.—As to the durability and cost of maintaining granite-block pavements in America no satisfactory statistics can be obtained.

The annual cost of maintenance in London varies from six to nineteen cents per square yard, depending upon the traffic. In Liverpool repairing costs four cents per annum, and cleaning and sprinkling fourteen cents. In London the cost of maintenance, including interest, etc., on first cost is from 25 to 69 cents per square yard per annum. In St. Louis, Mo., maintenance costs from ½ to 2½ cents per annum.

The average cost of maintaining granite-block pavements in the United States, irrespective of traffic tonnage, and exclusive of cleaning and sprinkling, appears to be about 1¼ cents per square yard per annum.

170. Method of Paying for Granite-block Pavements.—The present system of paying for granite-block paving is erroneous. The contractor buys his blocks at so much a thousand, and sells them at so much a square yard laid; thus it is his interest to have as few blocks to the square yard as possible and joints as large as he can. Or he may purchase them from the stone man at so much a square yard: in this case the stone man is interested in having as few blocks as possible; as is also the contractor, for the fewer blocks to be laid to the yard the more yards of paving will the pavior lay in a day, thus increasing the profits of the contractor. In some cases the pavior is paid by the square yard of paving; then it becomes his interest to have as few blocks to handle as possible and as wide joints as he may, thus increasing the number of square yards of paving he can lay in a day, and thereby increasing his wages. No matter how looked at, all parties concerned in furnishing and laying the blocks are deeply interested in having as few blocks and as wide joints as possible to the square yard. As both of these are serious defects, the temptation to adopt them should be removed. The number of blocks to be laid per square yard should be clearly stated in the specifications; a sum should also be designated to be deducted from the estimate, by way of a penalty or forfeit, for every block less that is used than the number called for. As the labor expended in ascertaining the number of blocks laid to each square

yard would be very great, it would be better to specify, as is the custom in Liverpool, that four courses of block shall not measure more than fourteen (14) inches. Under this rule the number of blocks laid can be very quickly determined by measuring any four courses at random over the length of the street.

City Engineer Horace Andrews of Albany has introduced with considerable success a reform in the manner of paying for granite block pavements.

The following unusual clauses are taken from his specifications, under which a large area of granite-block pavement has been laid:

"It is expressly understood and agreed, by and between the parties hereto, that the sum paid per square yard for granite block pavement shall be ascertained and fixed as follows—namely: The number of granite blocks per square yard, upon which the bid of the proposer is based, shall be 24. The actual average number of blocks laid per square yard by the contractor on the whole street shall be determined as follows: The City Engineer shall, from time to time, during the progress of the work, measure the width of the blocks as laid (by measuring the aggregate width of 50 to 100 courses, from this deducing the average width), which he shall combine with the average length of block as laid (hereby fixed and determined as 12¼ inches), for the purpose of computing the number of blocks laid per square yard.

"For each block, or fractional part thereof, that the average number laid per square yard shall exceed 24 there shall be added to the contractor's bid per square yard an amount computed at the rate of 9½ cents per block. For each block, or fractional part thereof, that the average number laid per square yard shall fall short of 24, there shall be deducted from the contractor's bid per square yard an amount computed at the rate of 9½ cents per block.

"In order to lay 24 to the square yard, the width of five courses, including the joints between the stones, should not exceed 22 inches."

The number of blocks specified per square yard differed on the individual streets; otherwise there were few changes in the above clauses.

The results obtained by the use of these clauses in the specifications during the last two years are indicated in the following

TABLE

SHOWING OPERATION OF SPECIFICATIONS REGARDING JOINTS IN GRANITE PAVEMENT IN 1890 AND 1891.

	Area in Square Yards.	Width of Five Courses as laid. Inches.	Number of Blocks laid per Square Yard.	Excess or Deficiency.	Contractor's Gain.	Contractor's Loss.
1	3,624	23.38	22.62	+0.12	$43.40	
2	1,588	23.13	22.87	+0.37	55.56	
3	879	23.50	22.50	0.00		
4	11,202	23.28	22.72	+0.22	238.61	
5	3.918	22.99	23.01	−1.99		$740.09
6	15,218	23.86	22.17	−0.33		471.75
7	1.641	24.57	21.53	−0.93		150.93
8	2,363	21.69	24.39	+0.39	87.44	
9	2,146	22.06	23.98	−0.02		4.29
10	2,679	24.18	21.88	−0.62		158.08
11	5,120	24.91	21.23	−1.27		614.38
12	2,846	23.31	22.70	−1.30		350.01

NOTE.—The specified number of blocks per square yard varied on different streets. It can be easily found from columns 4 and 5.

From an inspection of this table it is evident that close paving can be secured. Mr. Andrews believes that it might be more beneficial if the amount of deduction for non-fulfilment were increased, to guard against the contingency of wide blocks being obtainable at so low a rate as to make it profitable for a contractor to use them notwithstanding the deduction from his contract price per square yard.

171. Number of Granite Blocks per Square Yard.—Table XXVI shows the average number of granite blocks of different sizes

Width.	Length.	Average Number of Blocks per sq. yd. Exclusive of Joints.	Number of Square Yards 1 ton will cover at a depth of	
			7 inches.	9 inches.
3 inches	7 inches	62	2.50	2.00
3 "	9 "	48	"	"
3 "	10 "	4?	"	"
3 "	12 "	36	"	"
3½ "	7 "	53	"	"
3½ "	9 "	41	"	"
3½ "	10 "	37	"	"
3½ "	12 "	30	"	"

per square yard, and the average number of square yards that one ton of granite will cover, but these quantities will vary with the specific gravity of the stone employed.

172. Cost of Construction.—The cost of granite-block pavements varies greatly; it is materially affected by the weight of the blocks when their transportation for any considerable distance has to be

TABLE XXVII.

EXTENT AND COST OF GRANITE-BLOCK PAVEMENTS IN SEVERAL OF THE PRINCIPAL CITIES OF THE UNITED STATES IN 1890.

Cities.	Extent. Miles.	Cost of Construction per square yard.
New York, N. Y.	140.00	$2.50 to $4.50 †
Boston, Mass.	62.00	2.75 " 4.00 †
Brooklyn, N. Y.	55.30	2.75
St. Louis, Mo.	43.71	3.52
Atlanta, Ga.	33.00	1.50
Cincinnati, Ohio	30.00	4.25
Washington, D. C.	23.20	2.85 to 3.47 †
Chicago, Ill.	20.48	3.13
Richmond, Va.	16.58	2.48
Albany, N. Y.	16.39	2.78 to 3.45 †
Newark, N. J.	13.36	2.75
Lowell, Mass.	10.00	1.80 to 2.25
Providence, R. I.	9.20	2.50 " 4.00 †
Troy, N. Y.	9.12	
Milwaukee, Wis.	7.50	2.15 to 2.45
Worcester, Mass.	7.00	2.25
Omaha, Neb.	6.00	1.98
New Haven, Conn.	4.25	2 50
Minneapolis, Minn.	4.16	1.80 to 2.57
Cambridge, Mass.	3.63	2.20
Trenton, N. J.	3.50	3.00
Los Angeles, Cal.	1.50	2.52
Wilmington, N. C.	1.25	2.50
Nashville, Tenn.	1.25	3.15
Waterbury, Conn.	1.10	2.75 to 2.95
St. Paul, Minn.	0.39	2.10
*Toronto, Can.		3.00 to 3.85 †
*London (City), Eng.	29.00	3.60 " 4.08 †
" (Vestries), Eng.	251.00	
*Birmingham, Eng.	26.00	2.88
*Liverpool, "		3.75

* Foreign cities for comparison.

† Concrete foundation. Where not noted the foundation is either sand or gravel.

taken into account, by the character of the foundation and kind of joint-filling, and frequently by the condition of the labor market, demand, etc.

Tables XXVII, XXVIII, XXIX, and XXX show the extent and cost of granite-block, trap-block, sandstone-block, and cobblestone pavements in some of the principal cities of the United States in 1890.

TABLE XXVIII.

EXTENT AND COST OF BELGIAN BLOCK (TRAP) PAVEMENTS IN SOME OF THE PRINCIPAL CITIES OF THE UNITED STATES IN 1890.

Cities.	Extent. Miles.	Cost of Construction per square yard.
New York, N. Y.	199.07	$2.50
Philadelphia, Pa.	119.60	2.37
Brooklyn, N. Y.	22.41	
Paterson, N. J.	2.75	1.80 to $2.14
Camden, N. J.	2.08	2.00
Albany, N. Y.	1.42	2.60
Kingston, N. Y.	1.90	

TABLE XXIX.

EXTENT AND COST OF SANDSTONE-BLOCK PAVEMENTS IN SOME OF THE PRINCIPAL CITIES OF THE UNITED STATES IN 1890.

Cities.	Extent. Miles.	Cost of Construction per square yard.
Buffalo, N. Y.	188.00	$2.00
Toledo, Ohio	17.48	1.34
Rochester, N. Y.	16.50	2.25
Omaha, Neb.	11.00	1.98
Erie, Pa.	6.81	2.78
Elmira, N. Y.	5.00	
Utica, N. Y.	4.63	
Lockport, N. Y.	4.00	
Syracuse, N. Y.	3.40	1.80 to $3.69 *
Columbus, Ohio		2.98 " 3.94 *

* Concrete foundation.

TABLE XXX.

EXTENT AND COST OF COBBLESTONE PAVEMENTS IN SOME OF THE PRINCIPAL CITIES OF THE UNITED STATES IN 1890.

Cities.	Extent. Miles.	Cost of Construction per square yard.
Philadelphia, Pa.	490.60	
Brooklyn, N. Y.	280.38	
Albany, N. Y.	35.81	
Milwaukee, Wis.	35.00	$0.85
New Orleans, La.	33.00	
Newark, N. J.	26.18	
Camden, N. J.	16.98	0.65 to 1.25
Detroit, Mich.	16.07	1.50
Schenectady, N. Y.	15.00	
Washington, D. C.	12.00	
Utica, N. Y.	10.71	
Providence, R. I.	10.30	1.25
Jersey City, N. J.	10.00	
Boston, Mass.	8.00	
Cumberland, Md.	7.00	
Troy, N. Y.	5 50	
New York, N. Y.	5.13	
Toledo, Ohio	4.62	
Trenton, N. J.	4.50	0.65
Poughkeepsie, N. Y.	4.25	
Syracuse, N. Y.	1.54	
Grand Rapids, Mich.	1.33	0.40
Oswego, N. Y.	1.30	
New Haven, Conn.	0.12	0.75

173. Heads of Specifications for Granite-block Pavement.

(1) *Preparation of Roadbed.*

(2) *Foundation.*

(3) *Quality of the Blocks.*—The paving-blocks shall be of syenite or granite from or other approved quarries. All the blocks shall be of the same quality as to hardness, color, and grain; no outcrop, soft, brittle, or laminated stone will be accepted. When stone is obtained from more than one quarry, that from each quarry shall be piled and laid in separate sections of the work. In no case shall the stones from different quarries be mixed.

(4) *Dressing.*—The blocks are to be split and dressed so as to present regular and true surfaces on all sides, with straight edges on top, bottom, and sides. All sides of the block must be free from depressions or projections, and all blocks whose faces vary more than one half inch from rectangular shape will be rejected.

(5) *Size of the Blocks.*—The blocks shall measure 3½ inches wide, 7 inches deep, and may vary between 9 and 12 inches in length. In no case will any variation in the width be permitted. In some cases, as paving around man-hole heads, etc., blocks of lesser depth may be required, and will be used as directed by the engineer.

(6) *Inspection and Culling.*—The blocks will be inspected after they are brought on the line of the work, and all blocks which in quality and dimensions do not conform strictly to these specifications will be rejected, and must be immediately removed from the line of the work. The contractor must furnish such laborers as may be necessary to aid the inspector in the examination and the culling of the blocks; and in case the contractor neglect or refuse to furnish said laborers, such laborers as in the opinion of the may be necessary will be employed by said , and the expense thus incurred by will be deducted and paid out of any money then due or which may thereafter become due to said contractor under the contract to which these specifications refer.

(7) *Cushion-coat.*—On the concrete foundation a layer of clean sharp sand free from moisture will be evenly spread to a depth of one half inch. The sand if not dry must be made so by the application of artificial heat, in such apparatus as may be suitable for the purpose and approved of by the engineer.

(8) *Laying the Blocks.*—The blocks will be bedded in the sand, laid stone to stone in parallel courses at right angles to the axis of the street (except at intersecting streets, where they will be laid on the diagonal as shown on the plans). Each course shall consist of blocks of uniform width and depth. The blocks shall be so laid that the longitudinal joints shall be broken by a lap of at least two inches.

(9) *Jointing.*—After the blocks are so laid, the joints between them shall be filled to a depth of two inches with clean, dry gravel, then rammed to an unyielding bearing with a hand rammer weighing not less than fifty pounds. All blocks which sink below the general level must be removed and replaced with blocks of greater depth. After the blocks are rammed the paving cement will be poured into the joints, to a depth of two inches; the joints will then be filled flush with gravel and the cement poured in until the

joints are filled and will absorb no more. Dry sand will then be poured along the joints and spread over the entire pavement. The quantity of paving cement required per square yard of pavement will not be less than four gallons. This quantity must be brought upon the ground, and whatever may remain after the completion of the work will be the property of the city. Any wastage of paving cement by pouring over the surface instead of between the blocks must be covered with a sufficient quantity of fine dry gravel to absorb it. The amount so wasted will be estimated, and the quantity so estimated must be replaced by the contractor at his expense.

(10) *Composition of Paving Cement.*—The paving cement will be composed of the residuum obtained from the direct distillation of coal-tar and creosote oil, in the proportion of fifty gallons of oil to one ton of residuum; the two ingredients will be melted together in suitable iron boilers having a capacity of not less than one ton. It shall be poured into the joints while in a boiling state.

(11) *Quality of the Gravel.*—The gravel used for filling the joints shall be free from sand, clay, or other objectionable substances; it shall be of such size as will pass entirely through a sieve of three quarters of an inch mesh and be retained by a quarter-inch mesh.

(12) *Materials to be Kept Dry.*—The stone for the pavement, the sand for the bed, and the gravel for the joints shall each and severally be laid only when dry and free from moisture. After being laid the contractor shall protect them from the weather until the joints have been filled with the paving cement; should they become moist from any cause previous to filling the joints with the said cement, the contractor shall at his own expense remove that portion of the work so moistened and replace and complete the same with dry materials.

(13) [illegible] Blocks [illegible] *Railway Tracks*, etc. Between, and one foot outside of railroad tracks, over vaults, around sewer-manhole frames, and in such other places as the engineer may designate, the contractor shall furnish and use for the pavement blocks of such lesser depths as the engineer may direct. The general dimensions of such blocks on the top surface shall be the same as for the main pavement.

(14) The number of blocks laid per square yard shall be thirty, [illegible] measured lengthwise of the street shall [illegible] more than [illegible] inches. The actual average number of

granite blocks laid per square yard shall be ascertained by the city engineer; and for each block, or fractional part thereof, that the average number of blocks laid per square yard shall fall short of thirty there shall be deducted from the contractor's bid price an amount computed at cents for each block less than thirty.

(15) Interpretation of specifications.
(16) Omissions in specifications.
(17) Engineer defined.
(18) Contractor defined.
(19) Notice to contractors, how served.
(20) Preservation of engineer's marks, etc.
(21) Dismissal of incompetent persons.
(22) Quality of materials.
(23) Samples.
(24) Inspectors.
(25) Defective work, responsibility for.
(26) Measurements.
(27) Partial payments.
(28) Commencement of work.
(29) Time of completion.
(30) Forfeiture of contract.
(31) Damages for non-completion.
(32) Evidence of the payment of claims.
(33) Protection of persons and property.
(34) Bond for faithful performance of work.
(35) Power to suspend work.
(36) Right to construct sewers, etc.
(37) Loss and damage.
(38) Old materials, disposal of.
(39) Cleaning up.
(40) Personal attention of contractor.
(41) Payment of workmen.
(42) Prices.
(43) Security retained for repairs.
(44) Payment, when made. Final acceptance.

CHAPTER IV.

WOOD PAVEMENTS.

174. Wood Pavements.—Pavements formed of wood have been extensively employed both in Europe and the United States, but with widely differing results in the two countries. The experience in the United States has been, with but few exceptions, unsatisfactory, while in Europe, especially in the city of London, wood pavements have proved very successful and are quite popular.

175. The success of wood pavements in Europe is due to the fact that more care is exercised in their construction and maintenance. There, a solid concrete foundation, well-seasoned wood, and water-proof cement filling for the joints are employed, with constant and careful attention to keep them in repair.

176. The unsatisfactory results obtained in the United States are attributable, first, to the methods of construction; second, to the employment of green wood; and third, to the lack of careful maintenance.

177. The advantages of wood pavement may be stated as follows:

(1) It affords good foothold for horses.

(2) It offers less resistance to traction than stone and slightly more than asphalt.

(3) It suits all classes of traffic.

(4) It may be used on grades up to five per cent.

(5) It is moderately durable.

(6) It yields no mud when laid upon an impervious foundation.

(7) It yields but little dust.

(8) It is moderate in first cost.

(9) It is not disagreeably noisy.

178. The principal objections to wood pavement are:

(1) It is difficult to cleanse.

(2) Under certain conditions of the atmosphere it becomes greasy and very unsafe for horses.

(3) It is not easy to open for the purpose of gaining access to underground pipes, and rather a large surface has to be removed for this purpose, and it has to be left a little time after being repaired before traffic is again allowed upon it.

(4) It is absorbent of moisture.

(5) It is claimed by many that wood pavements are unhealthy.

179. Objections to Wooden Pavements on Hygienic Grounds.—Dr. O. W. Wight, Health Officer of Detroit, in a report to the City Council, says:

"On sanitary grounds, therefore, I must earnestly protest against the use of wooden-block pavements. Such blocks, laid endwise, not only absorb water which dissolves out the albuminoid matter that acts as a putrefactive leaven, but also absorbs an infusion of horse-manure and a great quantity of horse-urine dropped in the street. The lower end of the blocks, resting on boards, clay, or sand, soon becomes covered with an abundant fungoid growth, thoroughly saturated with albuminous extract and the excreta of animals in a liquid putrescible form. These wooden pavements undergo a decomposition in the warm season, and add to the unwholesomeness of the city. The street, in fact, might as well be covered a foot deep with rotting barnyard manure, so far as unwholesomeness is concerned. Moreover, the interstices between the blocks and the perforation of decay allow the foul liquids of the surface to flow through, supersaturating the earth beneath, and constantly adding to the putrefying mass."

M. Fonssagrivs, Professor of Hygiene at Montpellier, France, objects to wooden pavements because they "consist of a porous substance capable of absorbing organic matter and by its own decomposition giving rise to noxious miasma, which, proceeding from so large a surface, cannot be regarded as insignificant. I am convinced that a city with a damp climate, paved entirely with wood, would become a city of marsh-fever."

Professor Brewer, of Yale College, says that "even in the free air and full sunlight, along with the putrescence a white fungous growth begins on the surface of the wood, which rapidly becomes slimy. This forms much more rapidly on the ends of the grain of the wood than on the radial or tangential sides. The fungous growth goes on, modified, of course, by the temperature and the degree of concentration, and it continues for an unknown period, or until the

decay has become complete. Heartwood and sapwood act essentially alike in this matter; the difference is one of degree rather than character."

The following comments are from the report of a Board appointed by the Legislature of New South Wales to inquire into the alleged deleterious effects of wood pavement supon the public health.

"The Board examined specimens of wood pavement as laid in the city of Sydney, taking up blocks at different points. In all cases the concrete bed underneath was moist; in three cases a large amount of slimy mud was found giving off an ammoniacal odor. In all these the joints and blocks appeared to be uninjured. The blocks were chemically examined to determine whether they had absorbed organic matter, with the result that some were found impregnated with filth to the very centre, while others were comparatively free from it.

"The Board comes to the conclusion that wood is a material which cannot safely be used for paving unless it can be rendered absolutely impermeable to moisture, and so laid that while the entrance of water between the blocks is rendered impossible, the separation of the fibres at the surface by the concussion of traffic is also effectually prevented. These conditions have nowhere, to the knowledge of your Board, been fulfilled.

"So far as the careful researches of your Board go, the porous, absorbent, and destructible nature of wood must, in its opinion, be declared to be irremediable by any process at present known; nor, were any such process discovered, would it be effectual unless it were supplemented by another which should prevent fraying of the fibres. Still less can the defects of wood be considered to be of less consequence than the defects of other kinds of material.

"In this city it may perhaps be considered that an amount of wood has not yet been laid sufficient to affect the public health whatever its condition within reasonable limits may be; and upon this ground your Board does not recommend that the present paving should be removed, but that the Board of Health should be empowered to examine it, and to report upon it, from time to time, with a view of ascertaining its behavior under longer exposure to weather and traffic than it has yet had, and that it should be no longer watered, but cleansed by sweeping at least twice a day (the sweeping to be done at right angles to the direction of the street, or

parallel to the courses, so that the latter may be cleared out by the broom), in order that destructive dampness and penetration of dissolved organic matter may be reduced as much as possible. But the presumption is, upon the evidence here adduced, that in this climate the results alluded to would ensue if the extent of surface were sufficiently enlarged or fouling and decay sufficiently extensive. Your Board therefore recommends that the paving of the streets of this city with wood should be discontinued, and desires to add that this recommendation is extended to apply not to the particular mode of construction here adopted alone, but to the material itself, and to every known method of construction."

180. Opinion of Col. Haywood, Engineer of the City of London.—"It has been said that wood pavements at times smell offensively and may be unhealthy; but although some city streets have been paved with wood for thirty years, no complaints that I am aware of have been made to the commission on this head, and the inhabitants at all times have not only expressed great anxiety lest the wood should be replaced by other materials, but have subscribed toward the cost of its renewal. . . . I have at times noticed offensive emanations from it near cab-stands, but am unable to find further evidence of its unhealthiness. These remarks must be held to apply only to public streets open to the sun, air, and traffic; in confined places and under some conditions wood might be objectionable. I have seen it decaying in confined places without traffic."

181. Wood Pavements and Death-rate.—A comparison of the death rate in cities using wood pavements with that in cities where little or no wood is employed seems to show that wood pavements do not cause an increase in the death-rate.

Death-rate per 1000.	City.	Percentage of Wood Pavements.
17.48	Chicago	80
25.19	New York	0
23.31	Boston	0
19.74	Philadelphia	0
14.70	Detroit	91
16.90	Milwaukee	48
23.70	Nashville	0
19.87	Atlanta	0
9.17	Duluth	95

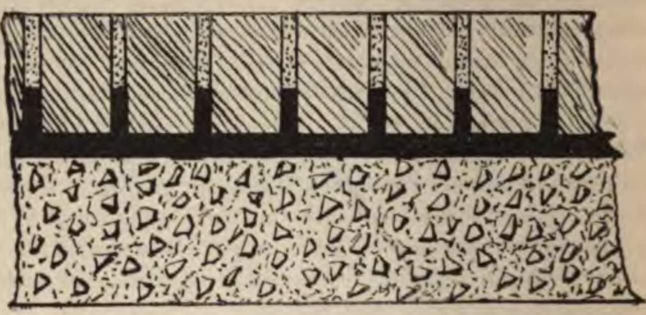


Fig. 12 SECTION SHOWING JOINT FILLING

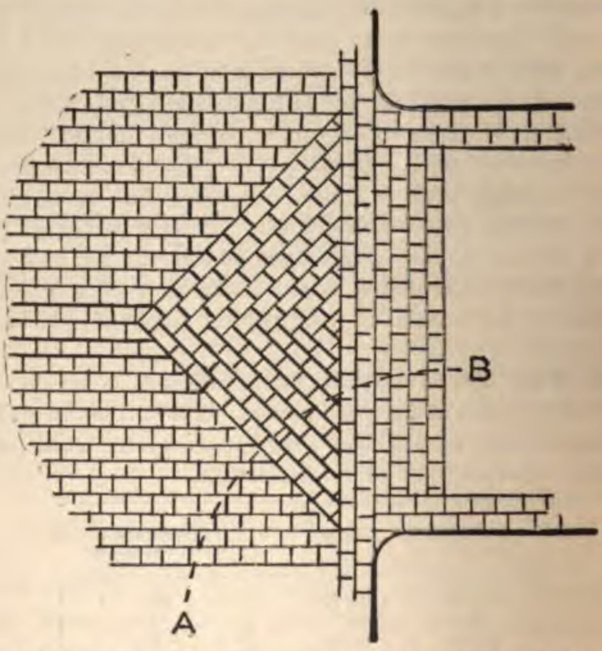


FIG. 13. PLAN OF STREET PAVED WITH WOOD BLOCKS.

SHOWING ARRANGEMENT OF BLOCKS AT STREET JUNCTIONS. A B SHOW THE LINE OF TRAVEL IN TURNING CORNERS.

182. Variety of Systems.—Since the introduction of wood for paving, upwards of forty patented systems of construction have been experimented with. The difference between these systems consisted in the shape of the blocks and the treatment of the wood with chemicals. The shape given to the block has been very varied; round, square, rectangular, oblique, hexagonal, octagonal, and many complicated forms and interlocking devices have been tried. But experience has demonstrated that with a solid foundation there is no reason for complicated shapes or interlocking contrivances; and wood pavements in their modern form consist of either rectangular or cylindrical blocks set with the fibre of the wood vertical, with the joints between the blocks as narrow as possible and filled with a water-proof cement.

The rectangular blocks are prepared by cutting with circular saws blocks of the required depth from planks 3 inches thick by 9 or 12 inches wide.

The cylindrical blocks are prepared by sawing from round logs pieces of the required length, usually 6 inches. These 6-inch pieces are passed through cylinders furnished with steel knives that remove the bark and sap-wood, and leave the blocks perfectly round and free from all unevenness. Figs. 12 and 13 show the manner of

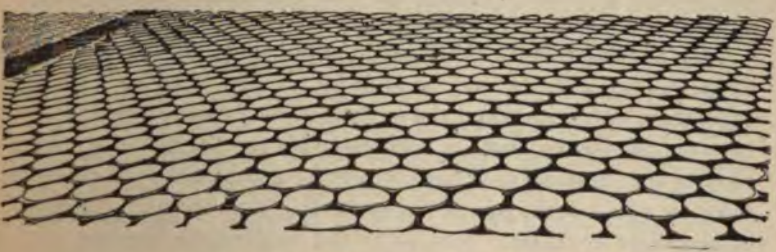


FIG. 13A. PAVEMENT OF ROUND BLOCKS.

constructing wood pavements as practiced in Europe. Fig. 13*a* shows a typical pavement of round blocks as laid in the United States.

183. Number of Wood Blocks per Square Yard.—The number of rectangular blocks 9 inches long by 3 inches wide required per square yard is 44, and the area occupied by the joints will be equal to 108 square inches.

The number of round blocks 6 inches in diameter required per square yard is 30, and the area occupied by interspaces will be 278.28 square inches.

184. The essentials necessary to the successful construction of wood pavements may be summed up as follows:

(1) An unyielding and impervious foundation (concrete).

(2) Sound and seasoned wood, either in its natural state or treated with a preserving compound.

(3) An impervious filling for the joints between the blocks.

185. Foundations.—As with all other paving materials so with wood, without an unyielding foundation it is impossible to preserve a smooth surface. The foundations most commonly employed in the United States are wanting in solidity; in the majority of cases the blocks are set in sand spread on the natural soil; in others they are set on one or two layers of plank laid on sand. The advantage claimed for the first method is cheapness; the advantages claimed for the second method are, first, that the flooring of planks distributes the weight or pressure applied to one block over a large surface, and, second, that the boards by their elastic action reduce the wear of the blocks. This latter claim is fallacious and inconsistent with the method of construction, for the sand bed on which the planks are laid is supposed to solidly support them, if it does so the planks cannot yield elastically under pressure.

186. The Chief Cause of Failure in pavements laid on a foundation of sand and planks is that, as soon as leakage, even to the slightest extent, commences and the surface-water finds its way downward between the blocks, there is nothing to prevent its reaching and saturating the substratum of sand; since the boards, although close-laid, have not water-tight joints, the water will pass through them with comparative freedom. The saturated substratum becomes mobile and subject to movement under variations of pressure. Consequently when a load passes over the surface, the boards, opposing an inconsiderable resistance to deflection, are pressed downwards by the load, and they recover their normal position when the load passes away. In this manner a pumping action is set up, and the sand and water, mixed with other loose matter at the bottom, is pumped up to the surface in the form of mud and slime. Thus the pavement becomes gradually undermined, and the undermining process is accelerated by the form of the pavement itself, which

presents a continuous diaphragm under which the exhausting process is extended as by a diaphragm-pump. The wetter the weather the greater is the action of undermining.

In addition to the general liability of leakage through the pavement, there is a special difficulty in keeping it water-tight at the curb, where it is comparatively overhung and unsupported, and where there is at the same time a constant supply of water for penetration so long as there is any water in the gutter.

A serious consequence of the flexibility of the pavement is the numerous breakages of the blocks by splitting, caused by the unequal strain and leverage of the load on blocks which are supported by a floor partly non-resisting and partly resisting.

187. Quality of Wood.—The question as to which of the various kinds of wood available is the most durable and economical has not been satisfactorily determined. Many varieties have been tried. In England preference is given to Baltic fir, yellow pine, and Swedish yellow deal. In the United States the variety most used (on account of its abundance and cheapness) is cedar; yellow pine, tamarack, and mesquite have also been used to a limited extent. Cypress and juniper are being largely used in some of the Southern States.

Hard woods, such as oak, etc., do not make the best pavements; such woods become slippery. The softer, close-grained woods, such as cedar, cypress, and pine, wear better and give good foothold.

The wood employed should be sound and seasoned, free from sap, shakes, and knots. Deflective blocks laid in the pavement will quickly cause holes in the surface, and the adjoining blocks will suffer under wear and the whole surface will become bumpy.

188. Chemical Treatment of Wood.—The great enemy of all wood pavements is decay, induced by the action of the air and water. Wood is porous, absorbs moisture, and thus hastens its own destruction. Many processes have been invented to overcome this defect, such as:

(1) *Burnettizing.*—This process consists in impregnating the wood with a solution of 1 pound of chloride of zinc to 4 gallons of water. Timber treated by simple immersion requires to remain in the solution for about two days for each inch in thickness, and after removal requires to be left to dry for about 14 to 20 days.

The process is more expeditiously performed by forcing the

solution into the pores of the wood with a pressure of 150 pounds to the square inch.

The chief advantage of this process is that it renders the wood incombustible.

(2) *Kyanizing.*—In this process the timber is immersed in a saturated solution of corrosive sublimate (bichloride of mercury) in a wooden tank, put together so that no metal of any kind can come in contact with the solution.

One pound of corrosive sublimate to 10 gallons of water is used when a maximum strength is required, and 1 pound to 15 gallons of water when a minimum, according to the porosity of the timber: with the latter proportion, 1¼ pounds will be sufficient for 50 cubic feet of timber.

The time required to saturate the timber depends on its thickness. Twenty-four hours are usually allowed for each inch in thickness for boards and small timber; large timber requires from a fortnight to three weeks.

(3) *Creosoting.*—This process consists in impregnating the wood with the oil of tar called *creosote,* from which the ammonia has been expelled, the effect being to coagulate the albumen and thereby prevent its decomposition, also to fill the pores of the wood with a bituminous substance that excludes both air and moisture, and which is noxious to the lower forms of animal and vegetable life. In adopting this process all moisture should be dried out of the pores of the timber. The softer woods, while warm from the drying-house, may be immersed at once in an open tank containing hot creosote oil, when they will absorb about 8 or 9 pounds per cubic foot. For hard woods, and woods which are required to absorb more than 8 or 9 pounds of creosote per cubic foot, the timber should be placed in an iron cylinder with closed ends, and the creosote, which should be heated to a temperature of about 120° Fahr., forced in with a pressure of 170 pounds to the square inch. The heat must be kept up until the process is complete, to prevent the creosote from crystallizing in the pores of the wood. By this means the softer woods will easily absorb from 10 to 12 pounds of the oil per cubic foot.

The most effective method, however, is to exhaust the air from the cylinder after the timber is inserted, then to allow the oil to flow in, and when the cylinder is full to use a force-pump with a

pressure of 150 to 200 pounds per square inch, until the wood has absorbed the requisite quantity of oil, as indicated by a gauge which should be fitted to the reservoir-tank.

The oil is usually heated by coils of pipe placed in the reservoir, through which a current of steam is passed.

The quantity of creosote oil recommended to be forced into the wood is from 8 to 12 pounds per cubic foot.

Into oak and other hard woods it is difficult to force, even with the greatest pressure, more than 2 or 3 pounds of that oil.

The advantages of this process are, the chemical constituents of the oil preserve the fibres of the wood by coagulating the albumen of the sap; the fatty matters act mechanically by filling the pores and thus exclude water; while the carbolic acid contained in the oil is a powerful disinfectant.

The life of the wood is extended by any of the above processes by preserving it from decay, but such processes have little or no effect on the wear of the blocks under traffic.

The process of dipping the blocks in coal-tar or creosote oil is injurious; besides affording a cover for the use of defective or sappy wood it hastens decay, especially of green wood; it closes up the exterior of the cells of the wood so that moisture cannot escape, thus causing fermentation to take place in the interior of the block, which quickly destroys the strength of the fibres and reduces them to punk.

The best European practice of to-day favors untreated blocks.

Considering the fact that in the United States large quantities of seasoned timber for paving cannot be obtained, it seems advisable that some artificial process of seasoning be employed. The most desirable process from an economic and sanitary point of view is the process of impregnation with oil of creosote. The success of this process depends upon the elimination of all moisture from the wood before the oil can be injected.

The woods which are best adapted to this treatment are those which are most absorbent and therefore the easiest and quickest destroyed, as the gums and cottonwoods. Cypress, cedar, pine, and porous oak are absorbent and can be successfully treated.

The cost of creosoting is about from \$12 to \$18 per 1000 feet, board measure.

189. Dimensions of the Blocks.—As with the stone-block pave-

ments so with wood blocks, the gauge of a horse's hoof is the measure of the maximum width. After numerous experiments with widths varying from 3 inches to 4½ inches, European engineers have decided upon the following dimensions: for rectangular blocks, width 3 inches, depth 6 inches, length 9 inches.

The advantage of the narrower width is that, besides affording a more ready foothold when the pavement is slippery, narrow blocks have more stability than wide ones of the same depth.

The length of a block should be suitably proportioned to the width; a length of 12 inches has been tried and found to be too much: the blocks were subject to splitting across. Nine inches appears to be the most suitable length.

For round blocks the diameter should not exceed 6 inches; the depth may be the same as for the rectangular blocks, 6 inches. There is no advantage gained by a greater depth, for few wood pavements under the most favorable conditions retain a sufficiently good surface after about six years' wear without extensive repairs, and it is therefore not advantageous to lay blocks of a greater depth than will provide for a duration of seven years. Six inches is sufficient for this.

190. Expansion of Blocks.—Wood blocks expand on exposure to moisture, and when laid end to end across the street the curbstones are liable to be displaced, or the courses of blocks will be bent into reverse curves. To avoid this the joints of the courses near the curb may be left open, or the courses next the curb may be left out until expansion has ceased, the space being temporarily filled with sand. The rate of expansion is about 1 inch in 8 feet, but varies for different woods. The time required for the wood to become fully expanded varies from 12 to 18 months. By employing blocks impregnated with the oil of creosote this trouble will be avoided. Blocks so treated do not contract or expand to any appreciable extent.

191. Width of Joints.—Experience has demonstrated that the wide joints once thought necessary for foothold are not required. The best European practice of to-day is to make the joints as near one quarter of an inch as possible. Wide joints hasten the destruction of the wood by permitting fibres to spread under the traffic.

192. Filling for Joints.—The best materials for filling the joints are bitumen for the lower two or three inches, and hy-

draulic cement-grout for the remainder of the depth. The cement-grout protects the pitch from the action of the sun and does not wear down very much below the surface of the wood.

193. Durability.—That wood pavements formed of well-seasoned wood properly laid on an unyielding foundation, with water-proof joints between the blocks, may last for many years without suffering decomposition, has been amply demonstrated by the experience had with wood pavements in the city of London and other European cities.

From the following table and remarks it will be seen that the durability of wood pavements in London varies from 5 to 19 years, while in the United States it varies from 3 to 7 years.

Table XXXI shows the actual duration and cost of certain wood pavements in the city of London.

TABLE XXXI.

DURATION AND COST OF WOOD PAVEMENTS IN THE CITY OF LONDON.*

(Foundations are included, but no excavation.)

Situation.	Date when laid new.	Life. yrs.	Life. ms.	First Cost per square yard.	Total Cost of Repairs per sq. yd. during life.	Average Cost per sq. yd. per annum.
Cornhill	May 1855	10	2	$2.92	$4.17	$0.70
	July 1865	6	8	2.76	2.35	0.73
Gracechurch St.	Nov. 1853	11	7	3.04	4.11	0.61
	June 1865	6	0	2.76	1.66	0.73
Lombard Street	May 1851	9	4	2.28	1.44	0.39
	Sept. 1860	10	7	2.20	4.90	0.66
Lothbury Street	May 1854	12	3	3.00	6.87	0.80
	Sept. 1860	6	1	3.00	0.83	0.63
Mincing Lane	July 1841	19	1	3.44	3.20	0.35
	Aug. 1860	13	0	2.20	5.47	0.59
Bartholomew Lane	May 1854	12	3	3.00	4.19	0.59
	Aug. 1866	5	5	3.00	0.95	0.73

* Report of Col. Haywood.

"The average life of the pavements in the three streets with the largest traffic was about 9 years, that of the three streets with the least traffic about 11¼ years. Nearly all before they were removed

had been relaid over their entire surface, and some new wood introduced from time to time in lieu of that found too defective to relay."

"It will be observed that the wood pavements last removed had a shorter life than the previous pavements. There is more than one reason for this, but it should be stated that nearly all would by relay and the introduction of some new wood have endured a few years longer."

194. The wood pavements of Berlin have not proved as durable as those of London and Paris, and their use is practically abandoned. Those of Frankfort (Ger.) laid under the Kerr system are giving satisfaction, and are said to be in as good condition to-day as when laid five years ago. The traffic on them is said to be constant and heavy.

195. W. Weaver, Chief Engineer and Surveyor, Kensington, London, says wood pavement of 5-inch creosote blocks will last ten years.

196. In Chicago, Ill., in some streets wood pavements have lasted upward of ten years; in others they have become very rough and uneven in three or four years, while in the river-tunnels they have worn out in two years.

197. The wood pavements of Washington, D. C., were of green hemlock, very badly constructed, and were destroyed by decay and dry-rot in about four years.

198. In St. Louis, Mo., the average life of the Nicholson pavements was six years. Burnettized cottonwood used on Broadway developed decay in the third year. Mr. George Burnet, Street Commissioner of St. Louis, in his annual report for 1890 recommends the use of cedar-block pavement for medium-traffic streets.

"Since 1884 the practice has been to lay gum and cottonwood blocks impregnated with chloride of zinc on a foundation of cement concrete 6 inches thick, and the joints filled with hot bituminous composition. The channels are formed by iron studs driven in the side of the blocks to the head, which is half an inch." (Thomas H. Macklind, District Engineer.)

199. In Detroit, Mich., the Board of Public Works consider that cedar-block pavements will last eight years before extensive repairs are necessary, but that it is better to make repairs earlier.

200. Mr. R. W. Roberts, City Surveyor of East Saginaw, Mich.,

in his report for 1889 says: "Eight to ten years is the estimated life of cedar-block pavement laid on sand and board foundation. Allowing that our pavements will last ten years, then during the next ten years this city will have to do all its paving over again at a cost equal to about 85 per cent of the first cost. Would it not be better to change from cedar-block pavements to something more durable, though the first cost is greater? On our business streets especially, the interruption of business by the tearing up and relaying of pavements is a thing to be considered in choosing our paving material."

201. According to the annual report for 1890 of the Board of Public Works of Duluth, Minn., 89,300 square yards of cedar-block pavement were laid in that year. The experience of the year shows that on grades between 4 and 13 per cent the best street surface is formed of blocks not more than 6 inches in diameter, laid in the usual manner, and with joints filled with grouting of Portland cement and sand. It has been found necessary to keep the surface-water on top of the pavements on grades exceeding 7 per cent. and on this account a concrete foundation is regarded as indispensable.

No tar composition was employed on the wood pavements in 1890, as its use was found to hasten rather than retard decay in the climate of Duluth, making the extra cost of about 17 cents per square yard an unnecessary expenditure. On levels and light grades the dust from the gravel strewed over the surface at the time of completion of the pavement soon worked into the joints, making an impervious roadway.

Owing to the fact that the subsoil of the streets in that city is a clay which causes the customary 3 inches of sand to be an insufficient foundation, most of the pavement laid in 1891 was built on a Telford foundation. This consists essentially of two layers of stone. The first is 6 inches thick, composed of large stones thoroughly wedged together, all chinks being filled with smaller stones, and the whole surface covered with a layer of wet gravel compacted by a 20-ton steam-roller. The second layer is 2 inches thick, composed of broken stone not more than 2 inches in greatest diameter, and covered with wet rolled gravel, like the first. On top of this foundation is sprinkled a thin layer of sand, which is covered by a course of 1-inch plank, affording a perfectly smooth and uniform surface on which to lay the blocks.

Such a foundation has been found in Duluth to have the advantage over concrete, which has heretofore been used on the best business streets, of having every portion of the sub-grade thoroughly compacted by the roller, the broken stone being forced down into the numerous soft spots. In preparing the subgrade for concrete foundations it was found that many spots had to be left unrolled, as they were too soft for the roller to pass over them. On the other hand, openings in Telford foundations for repairs to underground work cannot be as completely restored to their original condition as can concrete foundations, it being impracticable to thoroughly consolidate Telford macadam without the use of a heavy roller.

202. Wear.—The wear of wood pavements is generally considered to be as much due to the action of the horses' feet as to that of the wheels, and the action of the former is more destructive on steep grades; the wear is also increased by wide joints.

The wear of wood pavements by the abrading action of traffic is stated by various authorities as follows:

TABLE XXXII.

WEAR OF WOOD PAVEMENTS.

Wear per annum under a traffic tonnage, per yard of width.		Locality and Authority.
1200 vehicles, per 12 hours....	.81 inch	King William Street, London. Col. Haywood.
1106 tons......................	⅛ "	Parliament Street, London. G. H. Stayton, Engineer.
1360 "	.456 "	Fleet Street, London. G. H. Stayton, Engineer.
279 "	.065 "	Sloane Street, London. G. H. Stayton, Engineer.
94,000 "	½ "	Great Howard Street, Liverpool. G. Dunscombe, Engineer.
302,000 tons	.58 "	

The wear in the latter years of the life of the wood was found to be greater than in the first years. The wear between street-car rails is about one third more than the remainder of the roadway.

203. St. Paul, Minn.—The cedar-block pavement laid in 1882, on a plank and sand foundation, shows after seven years' use a wear of 2 to 2½ inches under ordinary traffic; on recent investiga-

tion the blocks showed very little decay, but the one-inch foundation-plank showed considerable. Two-inch planks are now used.

204. St. Louis, Mo.—On Third Street, with a traffic of 2400 vehicles in 24 hours, 6-inch blocks of prepared cottonwood wore down 1¼ inches in seven years.

205. The cost of construction of wood pavements ranges between $1.00 and $4.00, depending upon the quality of the wood and whether it be plain or creosoted, and upon the character of the foundation.

Table XXXIII shows the cost in various localities in the United States.

TABLE XXXIII.

EXTENT AND COST OF WOOD PAVEMENTS IN VARIOUS LOCALITIES IN THE UNITED STATES.

Cities.	Extent. Miles.	Cost of Construction per square yard.
Chicago, Ill.	410.00	$1.15
Detroit, Mich.	116.19	1.82
St. Paul, Minn	35.97	$1.20 to $1.40
Milwaukee, Wis.	30.00	1.05 " 1.25
Minneapolis, Minn.	25.85	0.95 " 1.99
Omaha, Neb.	25.00	1.80
Springfield, Ill.	20.00	1.30
Grand Rapids, Mich.	14.63	1.00
Toledo, Ohio.	12.09	1.96
Washington, D. C.	0.60	
St. Louis, Mo	0.19	3.56†
Elmira, N. Y		3.06
St. Joseph, Mo.		1.53
East Saginaw, Mich.	16.59	1.40‡
*Toronto, Can.	109.57	1.10§ 1.80‖ 2.65¶ 1.40†
*London, Eng. (City)	6.00	$3.00 to $4.30
" " (Vestries)	47.00	
*Birmingham, Eng.	6.00	2.52
*Paris, France		4.60**

* Foreign cities for comparison.

† Treated blocks. ‡ Plank foundation. § Gravel foundation.

‖ Cedar on concrete. ¶ Tamarack on concrete.

** Includes about 30 cents for the municipal tax on the material used.

206. Cost of Maintenance.—With regard to the cost of maintenance in the United States but little information can be obtained. St. Louis, Mo., reports the cost of maintaining pine-block pavement as 5 cents per square yard per annum, burnettized cottonwood at $4\frac{1}{2}$ to 6 cents. London, England, reports the cost of maintenance at from 16 to 36 cents per square yard per annum, or including all renewals 44 cents per annum. In Paris the cost ranges from 46 to 54 cents.

The practice of the companies engaged in the construction of wood pavements in Europe is to guarantee to keep the pavement in repair free of charge for one or two years, and then for so many years after at so much per annum. About $3.36 per square yard is generally the first cost of construction, and 24 cents the annual charge for maintenance.

Table XXXIV shows the annual cost of maintaining certain wood pavements in London.

TABLE XXXIV.

FIRST COST AND TENDERED COST PER ANNUM FOR MAINTAINING CERTAIN WOOD CARRIAGEWAY PAVEMENTS IN THE CITY OF LONDON.

Situation.	Date when laid.	Name of Contractor.	Years to be maintained by contractor.	First Cost per square yard.	Agreed Cost of Maintenance per square yard for the contract term.	Total Cost of Pavement during contract term per sq. yd.	Average Cost per sq. yd. per annum.
King William St.	Feb. 1873	Improved Wood. Pav. Co.	16	$4.32	1 yr. free, 15 yrs. at 36 cts.=$5.40	$9.72	$0.61
Ludgate Hill.	Nov. 1873	Ditto	16	4.32	1 yr. free, 15 yrs. at 36 cts.=$5.40	9.72	0.61
Portions of Great Tower St. and Seething Lane.	Sept. 1873	Ditto	16	3.84	1 yr. free, 15 yrs. at 30 cts.=$4.50	8 34	0.52

207. Assuming the life to be 7 years, Mr. Stayton estimates the annual cost of wood paving in Chelsea, England, with a traffic of 500 to 750 tons per square yard of width per day, to be 42 cents per square yard, which includes the cost of original construction, repairing, renewals, and interest spread over 15 years. Cleansing

and sanding are estimated to cost 10 cents per square yard in addition.

208. Description of Various Systems of Wood Paving.—Cedar-block Pavement, Detroit, Mich.—The cedar-block pavements used here are made of sound blocks, stripped of bark, cylindrical in shape and not more than 9 inches nor less than 5 inches in diameter and 7 inches deep. These blocks rest on a bed of bank sand and gravel 6 inches deep, well compacted with a roller weighing 2400 pounds. After the blocks are set they are rammed to a solid bearing with a rammer weighing 80 pounds; the spaces between them are filled with screened gravel rammed in with steel bars. The surface of the finished pavement is finally covered with gravel and sand to a depth of $\frac{3}{4}$ of an inch.

209. Mesquite-block Paving in San Antonio, Tex.—The blocks are hexagonal in shape, the minimum diameter being 4 inches and the maximum 8 inches, with a depth of 5 inches. The blocks are sawed with a slight batter, making the top about $\frac{1}{4}$ of an inch smaller than the bottom.

The roadbed is excavated to the required depth and rolled with a steam-roller.

The foundation is 6 inches of cement concrete. A cushion-coat of sand 1 inch in depth is spread over the concrete and the blocks bedded thereon. The joints are sand-filled. The cost per square yard, including foundation, is about \$2.80.

210. Asphalt Wood Pavement.—This is one of the more recently adopted pavements in England. It consists of a concrete foundation, on which is placed a coating of asphalt mastic one-half inch thick; the blocks are creosoted and are placed on the asphalt with spaces of half an inch between rows, and the joints are broken by a lap of at least two inches. The lower portion of the spaces for 2 to $2\frac{1}{2}$ inches up is filled with melted asphalt and the remainder with cement-grout and gravel. In London this costs \$4.00 per square yard.

211. Henson Pavement.—The Henson system, which has been largely used in London, is as follows: The blocks are bedded and jointed with ordinary roofing-felt, a strip of which, cut to a width equal to the depth of the blocks, is placed between every two courses. The joint is made as close as possible by driving up the blocks, as every eight or ten courses are laid, with heavy mallets, a plank being

laid along the face of the work; a perfectly close and slightly elastic joint is thus formed. A continuous layer of felt is likewise laid over the concrete foundation to give a slightly elastic bed to the blocks. The surface of the pavement is dressed over with a hot bituminous compound, and covered with fine clean grit. The blocks are laid in courses at right angles to the curb, any change in the latter being accommodated by shorter courses ending with wedge-shaped blocks. At street-intersections the courses are laid diagonally or meeting at right angles. Two or three courses are laid parallel with the curb to form the gutter.

212. Improved Wood-pavement Company.—The method employed by this company in constructing the wood pavements in Paris is as follows:

(1) *Foundation.*—This consists of a bed of Portland-cement beton 0.15 m. (6 inches) thick, with a top coat of cement mortar about 0.01 m. ($\frac{3}{8}$ inch) thick. The beton is thus proportioned: A mixture of about one third sand and two thirds gravel is put in a bottomless box containing half a cubic meter (0.65 cubic yard), and after the removal of the box 100 kilograms (220 pounds) of cement are emptied on the heap. This is in the proportion, by volume, of about one seventh as much cement as there is sand and gravel, since 1400 kilos is the mean weight of a cubic meter of good Portland cement heaped loosely.

The sand was dredged from the bed of the Seine, and the gravel taken from pits on the seashore. The cement was furnished by the manufactory of Demarle & Lonquety, of Boulogne-sur-Mer.

The paving-blocks have a uniform thickness and are not laid on the bed of beton until after it has set, in order to exactly preserve the curvature of the surface of the beton required for the convexity of the roadway. In the Avenue des Champs Élysées the convexity was 0.42 m. ($16\frac{1}{2}$ inches) in a width of 27 m. (87 feet 7 inches), which represents a mean transverse slope of a little more than 3 in 100. This convexity, though less than first proposed by the company, appears to be a little excessive, and it seems that for roads under satisfactory drainage conditions the convexity might be diminished: 0.42m. is only a mean convexity, for, on account of the small longitudinal slope of the avenue, the grade of the gutters is not parallel to the grade of the street, but presents a series of short slopes from the hydrants to the sewer-openings; consequently

the convexity varies from 0.39 m. (15¼ inches) at the hydrants to 0.45 m. (17¾ inches) at the sewers.

To exactly regulate the surface of the beton a series of transverse profiles were defined by stakes levelled to the grade of the top of the bed. Along each profile a strip of stiff beton was laid. The top of this beton was carefully levelled and smoothed and received a guide-rule, laid flat, whose thickness exactly corresponded with that of the beton coating. This series of rules thus formed a set of guides close together, between which it was easy with large straight-edges to level the beton to the required surface. The first levelling could never be more than approximate, the surface of the beton naturally remaining somewhat rough. The exact level required, as fixed by the tops of the rules, was secured by the top coat of cement mortar which filled the spaces between the pebbles and made an exact surface. This mortar was first composed of 200 kilos of cement to a cubic meter of sand (336 pounds to the cubic yard), but this proportion proving too small it was increased to 300 kilos. It was always mixed with a great excess of water, so as to penetrate the interstices of the gravel.

(2) *Paving.*—The covering is formed of small uniform blocks of red Northern fir, 0.15 m. (6 inches) high, 0.22 m. (8¾ inches) long, and 0.08 m. (3¼ inches) wide. These are set close lengthwise, with joints, transverse to the street, of about 1 centimeter (⅜ inch). The blocks are sent, ready for use, from England, where they were cut from planks of the ordinary size, 0.08 m. thick by 0.22 m. wide. The third dimension, taken in the length of the plank, forms the height of the block, so that in position the fibres of the wood are placed upright. The blocks are superficially creosoted after being cut.

When the foundation has set, two or three days after being laid, the blocks are set by the pavers. Owing to the light weight of the blocks the work of paving is very rapid. Between crossings the blocks are set in rows perpendicular to the axis of the street, with their longitudinal joints staggered exactly half the length of a block. The methods used at crossings to avoid a continuous joint parallel to the traffic are analogous to those used in stone-paving. Special precautions are taken to insure exact spacing and regularity of the rows. Before commencing a new row, a strip of wood whose thickness is exactly that of the required joint is set edgewise

in contact with the last row, and the paver has only to set the adjacent blocks in contact with it.

The blocks do not at first adhere to the foundation and are easily displaced after the removal of the strips; to maintain them in place, as soon as the strips are taken out a small quantity of bitumen is poured into the joints. This liquid material fills the small spaces that may exist under the blocks and partially fills the joints, and in solidifying effectually seals the blocks.

The joints are then filled by a thin grouting of neat Portland cement, distributed by the aid of a broom. This is done at least twice to insure perfect filling and the essential impermeability.

The pavement cannot be opened for traffic until after the cement in the joints has completely set, for which a delay of four or five days is considered necessary. During this interval the last operation is performed, viz., spreading a thin layer of dry sharp sand over the surface. The company claims that this dressing, crushed under the action of the wheels, incrusts itself in the wood and lends resistance to the wearing surface. It seems more probable that this coating is simply to protect the fresh mortar from the direct action of the wheels, for it can be maintained but a very short time on a travelled road, and is soon transformed into a disagreeable greasy mud.

213. Heads of Specifications for Wood-block Pavement.

(1) *Preparation of Roadbed.*

(2) *Foundation.*

(3) *Cushion-coat.*—The cushion-coat shall consist of a layer of dry, clean, sharp sand evenly spread on the concrete to a depth of one-half inch.

NOTE.—Asphaltic paving-cement may also be used for the cushion-coat; or the blocks may be laid directly upon the concrete.

(4) *Quality of the Blocks.*—The blocks shall be of timber, sound and thoroughly well seasoned, free from all sap, shakes, large and loose knots or other defects.

NOTE.—If the blocks are to be creosoted, the number of pounds of creosote that should be absorbed in a cubic foot of the wood should be specified; this is generally about 10 lbs. of creosote to 1 cubic foot of wood.

(5) *Size of the Blocks.*—(Rectangular:) The blocks must not be less than 6 inches nor more than 12 inches in length by 3 inches in

width and 6 inches in depth. (Round Blocks:) The blocks shall not be less than 4 inches nor more than 8 inches in diameter, with a uniform length of 6 inches. Each block to be of uniform cross-section from end to end, the ends to be sawn off at right angles to the axis. The diameter of the block preferred is 4 inches, and 70 per cent of the whole number of blocks furnished must be of this size.

(6) *Inspection and Culling.*—The blocks will be inspected after they are brought on the line of the work, and all blocks which in quality and dimensions do not conform strictly to these specifications will be rejected and must be immediately removed from the line of the work. The contractor must furnish such laborers as may be necessary to aid the inspector in the examination and culling of the blocks ; and in case the contractor neglect or refuse to furnish said laborers, such laborers as in the opinion of the may be necessary will be employed by said , and the expense thus incurred by will be deducted and paid out of any money then due or which may thereafter become due to said contractor under the contract to which these specifications refer.

(7) *Cushion-coat.*—On the concrete foundation a layer of clean sharp sand, free from moisture, will be evenly spread to a depth of one-half inch. The sand, if not dry, must be made so by the application of artificial heat in such apparatus as may be suitable for the purpose and approved of by the engineer.

(8) *Laying the Blocks.*—The blocks (rectangular) shall be set on the cushion-coat with the fibre vertical, in parallel courses, with the length of the blocks at right angles to the axis of the street; any change in the direction of the latter being accommodated by shorter courses ending in wedge-shaped blocks. No joints shall exceed ⅜ of an inch in width. The blocks shall be so laid that all longitudinal joints will be broken by a lap of at least 2 inches. At street-intersections the courses are to be laid diagonally as shown in Fig. 13.

The gutters will be formed by three courses of blocks laid parallel to the curb; the course adjoining the curb will be left out until expansion has ceased. The space so left unpaved will be filled with sand.

(9) *Laying the Blocks* (round blocks).—The blocks will be laid

on the cushion-coat, in parallel rows across the street and in close contact with each other. Split blocks shall be used adjoining the curbs, around sewer-manhole heads, and at such other places as the engineer may direct but no split blocks shall be laid in the main pavement.

(10) *Ramming.*—After the blocks are so laid they shall be rammed to a solid bearing with a hand rammer weighing not less than 50 pounds. All blocks which sink below the general level shall be taken out and sufficient sand poured in to bring them to the required level.

(11) *Jointing* (rectangular blocks).—The joints shall be carefully filled with a grout composed of two parts of fine, sharp, clean sand and one part of Portland cement of an approved brand.

(12) *Jointing* (round blocks).—The interstices between the blocks shall be filled for a depth of 2 inches from the bottom with clean, screened gravel, the pebbles of which shall not be less than ¼ inch nor more than ½ inch in diameter, then hot paving-cement shall be poured in to a depth of 2 inches and sufficient gravel poured in to fill the joints flush with the top of the pavement, then more paving cement poured in until the joints are full and will absorb no more. After which a layer half an inch deep of dry, sharp sand will be spread uniformly over the surface of the pavement.*

The quantity of paving-cement required per square yard will not be less than 3½ gallons. This quantity must be brought upon the ground, and whatever may remain after the completion of the work will be the property of the city. Any wastage of paving-cement by pouring over the surface instead of between the blocks must be covered with a sufficient quantity of fine dry gravel to absorb it. The amount so wasted will be estimated, and the quantity so estimated must be replaced by the contractor at his own expense.

(13) *Composition of Paving-cement.*—The paving-cement will be composed of the residuum obtained from the direct distillation of coal-tar and creosote oil, in the proportion of 50 gallons of oil to 1 ton of residuum. The two ingredients will be melted together in suitable iron boilers having a capacity of not less than 1 ton. The cement shall be poured into the joints when in a boiling state.

(14) *Quality of the Gravel.*—The gravel used for filling the

joints shall be free from sand, clay, or other objectionable substances.

(15) Interpretation of specifications.
(16) Omissions in specifications.
(17) Engineer defined.
(18) Contractor defined.
(19) Notice to contractors, how served.
(20) Preservation of engineer's marks, etc.
(21) Dismissal of incompetent persons.
(22) Quality of materials.
(23) Samples.
(24) Inspectors.
(25) Defective work.
(26) Measurements.
(27) Partial payments.
(28) Commencement of work.
(29) Time of completion.
(30) Forfeiture of contract.
(31) Damages for non-completion.
(32) Evidence of the payment of claims.
(33) Protection of persons and property.
(34) Indemnification for patent claims.
(35) Indemnity bond.
(36) Bond for faithful performance of work.
(37) Power to suspend work.
(38) Right to construct sewers, etc.
(39) Loss and damage.
(40) Old materials, disposal of.
(41) Cleaning up.
(42) Personal attention of contractor.
(43) Payment of workmen.
(44) Prices.
(45) Security retained for repairs.
(46) Payment, when made. Final acceptance.

214. Maintenance of Wood Pavements by Contract.—The contractor will undertake the maintenance of the pavement for years (usually eighteen) from day of 189 . This maintenance will consist in preserving the surface and regularity of the profile, and in making all general or partial repairs neces-

sary to keep the roadway in a perfect state, even if the dilapidations are the result of accidental causes, as fires, sinking of the subsoil, etc., excepting only defects caused by the digging of trenches.

The contractor will be required to make general repairs on all portions of the road where there is: (1) A reduction of the curve diminishing the original pitch by at least one fourth. (2) Where the thickness of the paving-blocks has been worn away $\frac{3}{4}$ of an inch or more. (3) Depressions or partial defects of the road numerous enough to make it rough, the engineer being judge of the time when it shall be required for this reason.

The concrete foundation will generally be preserved by simply adding Portland-cement mortar on top if there is room for it; the removal of the foundation is not obligatory except in case of its bad condition.

Besides the general repairs the contractor must insure the constant good state of the pavement by partial repairs that may be necessary. He must immediately replace paving-blocks that are decayed, crushed, broken, or depressed by any cause whatever, also those which have become impregnated with urine or other offensive liquids and emit a bad odor.

He must repair holes whose depth reaches $\frac{3}{4}$ of an inch for a length of 3 feet in any direction.

At the junction-lines of the wooden pavement with the stone or asphalt pavement, paving-blocks will be replaced when they shall have been worn away $\frac{7}{16}$ of an inch.

In all partial repairs the new pavement must have the same level as the adjacent pavement; no projections will be permitted. If any of the defects enumerated in this article are not repaired within three days after notification, a charge of   dollars per day will be deducted from the contract price for each day's delay.

Renewals of the pavement over trenches opened for any cause must be executed in the same time and under the same restrictions as above. The renewed portions will immediately pass into the maintenance of the contractor, who must preserve them in accordance with the foregoing conditions. No claims will be allowed for repairs required by sinking of the earth. The contractor will only be paid for the area of the trenches measured when filled up.

The old material and rubbish from repairs must be entirely

removed from the street on completion of the work, in default of which the contractor will be subjected to a penalty of dollars per day for each deposit not removed.

At the expiration of the maintenance period the pavement must be delivered in perfect condition. Three months before the expiration of the contract term the engineer will make a statement showing the condition of the pavement. The pavement shall not be received unless it satisfies the following requirements: (1) There must be no holes having a depth of $\frac{5}{8}$ of an inch in any square yard of the pavement. (2) The transverse contour of the surface must not at any point be reduced so that the rise is less than four fifths of its original value. (3) The thickness of the blocks must at no place be less than 2 inches. After the engineer's inspection and report the contractor will be allowed three months to place the work in the required condition.

The contract price fixed for the renewal of the pavement will be paid for the repairs over trenches, the demolition of the pavement being at the expense of the person or companies opening the trench. The contractor must, if necessary, relay the pavement with entirely new materials, and can make no claim for damages to the work or its maintenance.

The price to be paid for maintaining the pavement in the above-described condition is cents per square yard, and will be payable quarterly during the contract period. Ten percentum of the amount payable quarterly will be retained and shall not be due or payable until the expiration of the contract period.

The price to be paid per square yard for the renewal of the pavement over trenches is dollars.

215. Specifications for Laying Cedar Pavement in Chicago.—Before paving the street shall be graded to conform to stakes or profiles to be given by the engineer in charge, and thoroughly flooded, rammed, and rolled to give it a solid bed.

Paving.—1st. The pavement shall not be laid on any street until the material thereof shall have been made firm and unyielding, and the contractor shall assume all the responsibility therefor.

2d. A bed of clean lake-shore sand, not less than three (3) inches in depth, shall be smoothly and evenly spread over the surface of the street, and compactly rammed and rolled down.

3d. A foundation of two- (2-) inch sound common hemlock

plank, to be laid lengthwise of the street, close together upon one- (1-) inch by eight- (8-) inch pine stringers under the ends and centres. Stringers to be firmly bedded in the sand.

4th. Upon said foundation live cedar blocks, free from bark and perfectly sound, not less than four (4) inches nor more than eight (8) inches in diameter, and six (6) inches in length, shall be placed on end, close-laid, resting properly on their bases and well driven together. All blocks more than eight (8) inches in diameter shall be split and the corners cut sufficiently to make good joints with adjacent blocks.

No split blocks of less than three (3) inches in thickness will be allowed.

All knots or excrescences must be cut off to make the blocks practically uniform in diameter throughout their length.

No interstice between the blocks to be more than one and one-half ($1\frac{1}{2}$) inches nor less than three quarters ($\frac{3}{4}$) of an inch.

No square holes will be allowed, nor must two split sides come together.

The surface of the pavement must be true and uniform.

In case any loose or defective blocks shall be found in the pavement, they shall be removed and replaced by perfect blocks of proper size, and so much of the pavement as may be necessary to make the work perfect shall be taken up and relaid at the expense of the contractor.

The blocks will be carefully inspected after they are brought on the line of the work, and all blocks or other material which, in quality or dimensions, do not strictly conform with these specifications, or which may be otherwise defective, shall be rejected, and must be immediately removed from the line of the work by the contractor. The contractor will be required to furnish such laborers as may be necessary to aid the inspector in the examination and culling of the blocks and other material; and in case the contractor shall neglect or refuse so to do, such laborers as in the opinion of the Commissioner of Public Works may be necessary will be employed, and the expense incurred shall be deducted from any money then due or which thereafter may become due the contractor.

5th. The spaces between the blocks to be filled with clean, dry lake-shore gravel, of one fourth ($\frac{1}{4}$) to one (1) inch in size, the proportion of said gravel to be such as to completely fill the interstices,

and shall be thoroughly rammed with proper tools and by competent and experienced help, and again filled with the same kind of gravel and again thoroughly rammed.

In the above-described ramming the filling in each interstice must be struck three full blows and driven down well. Two competent rammers must be constantly employed after each paver. No teams will be allowed on the pavement before it is properly rammed. After ramming the pavement will be flooded with hot composition, not less than one and one half ($1\frac{1}{2}$) gallons per square yard being used. The tar will be distributed with a three- (3-) gallon kettle, the work to be done in sections as the Commissioner of Public Works, or his representative, may direct.

6th. After which clean, dry lake-shore gravel, about one fourth ($\frac{1}{4}$) inch in size, shall be spread over the street in such quantity that when swept all the interstices between the blocks will be thoroughly filled. When the gravel is put on the second and third time there must be enough space left between the portions rammed once and twice for the other portions to enable the inspector to see that every part of the street is thoroughly rammed.

7th. The whole surface will be swept over and covered with hot composition not less than one half ($\frac{1}{2}$) gallon per square yard, and immediately covered with dry roofing-gravel, or gravel screened from that used to fill the spaces between the blocks, said covering to be not less than one (1) inch thick. All gravel used here must be lake-shore gravel, entirely free from sand or pebbles, over one half ($\frac{1}{2}$) inch in size, and dried and heated enough to prevent the chilling of the composition. The gravelling and tarring must be completed each day to within fifteen (15) feet of the end of the paving, and the top dressing to within fifty (50) feet. If the gravel and pavement becomes wet before the tarring is completed, the same may be ordered taken by the Commissioner of Public Works.

The composition used will be furnished by the city in the ordinary portable tanks at some point within the city limits; the same to be transferred by the contractor from the receiving point to the work, and the empty tanks returned to the place of reception; the contractor to furnish the necessary fuel and labor to keep the composition at a temperature of not less than 300 degrees Fahrenheit, and be at all times responsible for the tanks and their contents while in his care. The Department reserves the right to increase or diminish the quantity of the composition used.

216. Extracts from the Specifications for Laying Cedar-block Pavements in Minneapolis.—*Street Railway.*—Upon such streets as the street-railway company has tracks, it shall be the duty of the street-railway company to lower its tracks to the grade of the pavement to be laid. The said street-railway company in lowering its tracks shall deposit the material excavated on the outside of its tracks, and the contractor will be required to remove the same at the same price per cubic yard as for extra excavation. It is, however, expressly understood that when the street-railway company has double tracks the contractor will be required to excavate and pave the spaces between said double tracks in the same manner as the remainder of the roadway, and shall receive the same price per square yard for said paving as he shall receive per square yard for the remainder of the paving of said roadway.

Blocks.—The blocks must be of the best quality of cedar, live and perfectly sound, and when in place be free from projecting knots and bark. They must be of a uniform length of six (6) inches, and have a diameter of not less than four (4) inches nor more than (10) ten inches. No blocks exceeding ten (10) inches in diameter will be allowed in the work either whole or split, and it is hereby expressly understood that the contractor will not be allowed to deposit upon the line of the work any blocks having the diameter greater than ten (10) inches, or any blocks turned from a post of a greater diameter than ten (10) inches.

It is expressly understood that the contractor will be required to repair in a satisfactory manner any paving that may settle or become defective on account of improper workmanship or material, or on account of the laying or construction of water-mains, sewers, gas-pipes, or making sewer, water, or gas connections, or conduit-laying, or any excavations allowed to be made in the street by the city council, which may have been done previous to the laying of said pavements, without cost to the city of Minneapolis.

Flooring.—Upon the finished sub-grade must be laid a floor of sound white-pine plank, of the quality equal to the grade known as first common lumber, as the city engineer and the city council may determine. These plank must be laid lengthwise of the street with close joints, and be two (2) inches thick, from eight (8) to twelve (12) inches wide, and from fourteen (14) to sixteen (16) feet long. They must have a bearing at each end and in the centre upon

a one- (1-) inch by eight- (8-) inch stringer firmly bedded in the sand. Planks not less than six (6) inches wide may, however, be used in order to form the crown of crossings.

Laying.—The blocks must be placed upon their ends in close contact with each other, on a clean floor. The joints between the blocks must not exceed two inches in their longest direction. Blocks of less diameter than six inches must not be split, nor must a piece of less size than half the block be used. The corners of split blocks must be trimmed so as to make proper joints. Unnecessary splitting of blocks will not be allowed.

Joints to be Filled.—The joints or spaces between the blocks must be filled in the following manner: First, fill the joints by sweeping clean, screened gravel, the pebbles of which shall be of a size not exceeding one inch in their largest diameter, into them. After sweeping, the surface of the pavement must be clean and free from gravel, then the gravel must be thoroughly tamped. This process must be repeated a second time. Gravel of the same kind as before used must be spread over the surface to a depth of not less than one inch above the top of the blocks.

Gutters and Corners of Crossings must be made as follows: The outside plank shall be 3 inches thick, 16 inches high, and 20 feet long on 80-foot streets, and 3 inches by 16 inches by 16 feet on 60-foot streets, and held in place by not less than six posts of 3 by 6 by 30 inches, driven to a depth of three inches below the top and equidistant along the length of the plank. There shall be a plank 2 inches thick, 10 feet long, for 80-foot streets, and 2 inches by 8 feet on 60-foot streets, and of a width of 3 inches less than the depth of the gutter, placed against the curb to support the gutter-cover, which shall be made of two pieces of 3 by 12 inches by 10 feet on 80-foot streets, and of 3 by 12 inches by 8 feet on 60-foot streets, fastened together with four pieces, 2 by 19 inches, well nailed with six 30d. spikes to each piece. The top of the outside gutter-plank on the slope of the crossing shall be trimmed to conform to the top of the paving. In making proposals the contractor will state a price which shall include cost of excavating eight (8) inches below the top of the finished paving; also the furnishing and putting in place complete of all lumber required in the gutter crossings and covers. The contractor will state a price per cubic yard for extra excavation.

CHAPTER V.

ASPHALTUM AND COAL-TAR PAVEMENTS.

217. Asphalt was first employed for street-paving in Paris in 1838, but it was not employed to any great extent until 1854. In 1869 it was introduced into London, and since then has been extensively used throughout Europe.

The success which attended this pavement led to its introduction into America. The great cost of importing the materials from Europe made the pavement so expensive as to induce American inventors to seek to manufacture a material which should have similar qualities. The result was the introduction of many substitutes and imitations, the majority of which proved defective.

The great cost of the imported material and the failure of the substitutes directed attention to the deposits of natural bitumen on the island of Trinidad, which could be brought here very cheaply. Experiments were made which demonstrated the possibility of making a mastic with Trinidad bitumen as its cementing material, as strong, elastic, and durable as that imported from Europe; but it was only after some years that this process was introduced and made a commercial success.

218. The difference between the asphalt pavements of Europe and those of America is due to the character of the materials. The former are composed of limestone rock naturally impregnated with bitumen, while the latter are composed of an artificial mixture of bitumen, limestone, and sand. The limestone in the European pavements becomes hard, smooth, and slippery under traffic, and is thus objectionable for general use in frosty latitudes. The granular nature of the sand used in preparing the Trinidad asphaltum diminishes the tendency to wear smooth and materially lessens the slipping of horses.

219. Although many deposits of bituminous rock are found in the United States, they have been used only to a limited extent,

and the island of Trinidad continues to be the main source of supply for the United States. This is due entirely to its advantage in cost of transportation. The railroad freight rates from the place of the deposits practically shut out the bituminous rock of California and Kentucky from competition in the Eastern States, and a similar condition may be said to affect the sale of Trinidad asphaltum in the cities of Europe, since the bituminous limestones of Val de Travers and Seyssel, having the advantage in freights, control the markets.

220. The cost of preparing the different varieties of asphaltum for street pavement is nearly the same; and as all appear to be about equally durable, the exclusive use of any one of them is due merely to the advantage in freights.

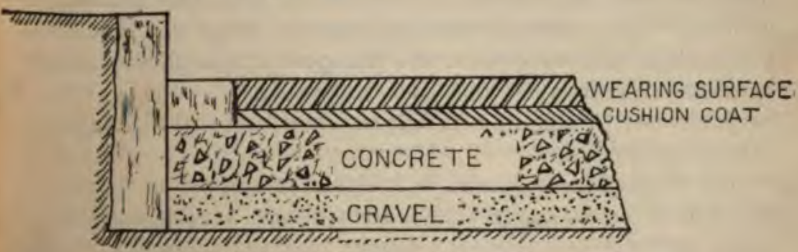


FIG. 14.—SECTION OF TRINIDAD ASPHALT PAVEMENT.

FIG. 15.—SECTION OF TRINIDAD ASPHALT ON BITUMINOUS BASE.

221. The Advantages of Asphalt may be summed up as follows:

(1) Ease of traction.

(2) It is comparatively noiseless under traffic.

(3) It is impervious.

(4) It is easily cleansed.

(5) It produces neither mud nor dust.

(6) It is pleasing to the eye.

(7) It suits all classes of traffic.

(8) There is neither vibration nor concussion in travelling over it.

(9) It is expeditiously laid, thereby causing little inconvenience to traffic.

(10) Openings to gain access to underground pipes are easily made.

(11) It is durable.

(12) It is easily repaired.

222. Defects of Asphalt Pavement.

(1) It is slippery under certain conditions of the atmosphere. The American asphalts are much less so than the European on account of their granular texture, derived from the sand. The difference is very noticeable: the European are as smooth as glass, while the American resemble fine sand-paper.

(2) It will not stand constant moisture, and will disintegrate if excessively sprinkled.

(3) Under extreme heat it is liable to become so soft that it will roll or creep under traffic and present a wavy surface, and under extreme cold there is a danger that the surface will crack and become friable. (In Washington, D. C., with a range of temperature from 5 to 150 degrees Fahr., no serious trouble has been experienced with the Trinidad asphalts.)

(4) It is not adapted to grades steeper than 2½ per cent.

(5) Repairs must be quickly made, for the material has little hardness, and if, from irregular settlement of the foundation or local violence, a break occurs, the passing wheels rapidly shear off the sides of the hole, and it soon assumes formidable dimensions. In London this is prevented by constant watchfulness. Workmen are employed to traverse the street with a light repairing outfit, and whenever a defect is observed it is patched at once, and so effectually that the spot cannot be distinguished.

223. The strewing of sand upon asphalt renders it less slippery; but in addition to the interference of the traffic whilst this is being done, there are further objections, viz., the possible injury by the sand cutting into the asphalt, the expense of labor and materials, and the mud caused thereby which has afterwards to be removed.

224. Although pure asphaltum is absolutely impervious and insoluble in either fresh or salt water, yet asphalt pavements in the continued presence of water are quickly disintegrated. Ordinary rain or daily sprinkling does not injure them when they are allowed to become perfectly dry again. The damage is most apparent in the gutters and adjacent to overflowing drinking-fountains. This defect has long been recognized, and various measures have been taken to overcome it, or at least to reduce it to the minimum. In some cities ordinances have been passed seeking to regulate the sprinkling of the streets, and in many places the gutters are laid with stone, while in others the asphalt is laid to the curb and a space of 12 to 15 inches along the curb is covered with a thin coating of asphalt cement. This latter mode is followed in Washington, D. C. It is said that the pavements formed of asphalt cement in which "Maltha" or liquid asphalt is used, instead of the residuum of petroleum, as the fluxing agent, are not affected by moisture.

225. Asphalt laid adjoining centre-bearing street-car rails is quickly broken down and destroyed. This defect is not peculiar to asphalt. All other materials when placed in similar positions are quickly worn. Granite blocks laid along such tracks have been cut into at a rate of more than half an inch a year. The frequent entering and turning off of vehicles from car-tracks is one of the severest tests that can be applied to any paving material; moreover, the gauge of trucks and vehicles is frequently greater than that of the rails, so one wheel runs on the rail and the other outside. The number of wheels thus travelling in one line must quickly wear a rut in any material adjoining the centre-bearing rail.

To obviate the destruction of asphalt in such situations it is usual to lay a strip of granite-block paving alongside of the rail. These blocks are laid alternately as headers and stretchers, so as to form a toothing into the asphalt. This pavement should be of sufficient width to support the wheels of the widest gauge using the street.

226. **Asphalt Pavement Injured by Illuminating-gas.**—The asphalt pavements on some of the streets of Frankfort, Germany, became friable and porous. City Engineer Dehnhardt attributed this to the escape of illuminating-gas. This view was ridiculed by several German authorities on this material. The pavements were

taken up, and it was found that the gas-pipes had several leaks under the worst parts of the street. Some of the injured pavement and pieces of sound pavement were tested. The sound fragments were placed in a tube through which gas was allowed to flow. After a week the samples were reduced to the same friable condition in which parts of the pavement had been found. The samples after several weeks' exposure to the atmosphere regained their original good condition. The explanation offered is that a portion of the carburetted hydrogen of the gas is absorbed by the asphalt, thus destroying its cohesion.

227. Durability.—The systems adopted for the maintenance of asphalt pavements renders it difficult to ascertain their actual life under traffic. They are repaired immediately they need it, and as each repair is so much new material laid, the whole surface is really relaid in the course of years. Col. Haywood states that in his opinion asphalt will last without extensive repairs from four to six years, and that in the course of ten years the entire surface will have been renewed.

228. That asphalt successfully sustains an enormous traffic is shown by the following figures: From London, Cheapside has a traffic of 13,772 vehicles in 24 hours; Mansion House Street, 23,332 vehicles in 24 hours. Cornhill, Holborn Viaduct, and many others have a daily traffic of upwards of 12,000 vehicles. These streets are paved with asphalt.

229. There are no streets in America or elsewhere in the world that have so much traffic as the above-mentioned London streets. Among the vehicles that travel on them are omnibuses loaded with passengers inside and out, light vehicles of all descriptions, carts, carriages, and brewery trucks loaded with tons of ale and porter.

Cheapside was paved in 1870, and the pavement remained in constant use for 19 years, with of course extensive repairs; but up to 1889 the carriageway was never closed entirely for a general relaying of the pavement. In 1889, the contract for maintenance of the asphalt having expired, a new contract was made and a new surface of asphalt was laid.

230. St. Louis, Mo.—"The asphalt laid on Pine Street in 1883 is now in good condition after a test of eight years under a mixed traffic of 3000 vehicles in 12 hours from 7 A.M. to 7 P.M. The work was carefully executed, and consists of a 6-inch hydraulic-cement

concrete base, one-half inch cushion-coat and 2-inch surface or wearing coat, cross-section camber 0.50, width between curbs 36 feet. Traffic is what may be termed building materials, residence supplies, and suburban. While it has been subjected to the heaviest loads hauled in the city with fair results, it must stand below granite for wear." (Report of Mr. T. H. Macklind, District Engineer.)

231. Wear.—Asphalt is to a certain extent elastic and does not begin to wear until this elasticity is overcome by thorough compression. This is the case with no other paving material. Stone and wood begin wearing from the day traffic commences. Under ordinary traffic it may be estimated that it will take two years to complete the compression of asphalt, and the weight of a square foot of this pavement will at the expiration of that time be nearly the same as on the day it was laid, though the thickness is reduced during the first two years as much as it will be in the following eight. The extent to which the thickness has been reduced is said to be as much as one fourth the original thickness.

A pavement in Paris which had lost more than one fourth of its thickness was found to have lost only 5% of its weight after 16 years' use.

The pavement in Cheapside, London, after fourteen years' use, shows a reduction, where not repaired, from its original thickness of $2\frac{1}{4}$ to $1\frac{5}{8}$ inches.

232. Cost of Construction.—The cost of construction varies with the locality, thickness of wearing surface, and kind of foundation.

Table XXXV shows the extent and cost in several cities in America.

In London the first cost is from $3.75 to $4.50 per square yard, including maintenance. The total annual expense varies from 33 to 57 cents per square yard.

In Omaha, Neb., the first cost per square yard, including maintenance for five years, is about $2.98.

The prices per square yard given in Table XXXV for American cities includes in nearly all cases the maintenance of the pavement for a period of five years.

TABLE XXXV.

EXTENT AND COST OF ASPHALT PAVEMENTS IN THE PRINCIPAL CITIES OF THE UNITED STATES IN 1890.

Cities.	Extent. Miles.	Cost of Construction per square yard.
Buffalo, N. Y.	83.00	$3.00
Washington, D. C.	49.70	
Philadelphia, Pa.	24.60	2.50
Omaha, Neb.	15.75	2.98
Brooklyn, N. Y.	8.82	
Rochester, N. Y.	8.00	
Detroit, Mich.	6.86	3.30
Utica, N. Y.	6.14	
St. Joseph, Mo.	6.00	2.80
Erie, Pa.	5.58	3.00
Chicago, Ill.	5.09	3.00
Toledo, Ohio	4.50	2.58
St. Paul, Minn.	4.04	2.75
St. Louis, Mo.	3.95	2.97
New York, N. Y.	3.36	3.25 to 4.50
Boston, Mass	2.70	3.50
Harrisburg, Pa.	2.50	2.78
Syracuse, N. Y.	1.79	2.70
Minneapolis, Minn.	0.98	2.75
Providence, R. I.	0.84	2.50
Schenectady, N. Y.	0.75	
Newark, N. J.	0.57	2.80
Troy, N. Y.	0.50	
Albany, N. Y.	0.46	
Los Angeles, Cal	0.30	2.56
New Haven, Conn.	0.25	2.75
Grand Rapids, Mich.	0.21	2.95
Milwaukee, Wis.	0.16	2.65
*Montreal, Can.		3.43 / 3.97
*Toronto, Can.	5.08	3.00
*Berlin, Ger.	45.00	3.50
*London (city)	13.00	3.75 to 4.50
*London (vestries)	10.00	" "
*Paris, France	22.50	4.00 to 4.30

* Foreign cities for comparison.

The extent of the asphalt pavement in use in 1890 was: United States, 6,803,054 square yards, equal to 446 miles of roadway 26 feet wide; Europe, 1,698,846, equal to 111.3 miles.

233. Cost of Maintenance.—Asphalt pavements are generally maintained by the companies that construct them. The systems adopted are as follows:

The company constructing the pavement undertake to maintain

it in good condition for a fixed number of years. In America the cost of maintenance is included in the price paid for the construction, and the period varies from five to fifteen years.

In Europe a fixed price is paid for construction, and the company maintain the surface free for two years, after which period they are paid a certain amount annually per square yard, depending upon the amount of the traffic over the pavement, for maintaining it in good condition (usually fifteen years); in case of any disturbance of the pavement by a corporation or by a private citizen, the company replaces the pavement at the expense of such corporation or citizen, and is responsible for the maintenance thereafter.

A force of men is kept constantly at work making repairs, and any defect, however slight, is repaired immediately.

It is not considered that the necessity for continual repairs is an evidence of poor workmanship in the original construction or of defective materials used, but rather that an earnest endeavor is being made to keep the pavement, even under heavy traffic, at all times in perfect order. This prompt and constant repairing explains the superior condition of the pavements in the cities of Europe.

234. The average cost of maintaining asphalt pavements in London for an average of fifteen years is as follows:

Val de Travers	24 cents per annum
Limmer	19 " " "
Société Française	22 " " "

The average cost in America is placed at 10 cents per square yard per annum.

235. In St. Louis, Mo., maintenance under contract varies between 4½ and 9 cents per square yard per annum, the period contracted for being ten years,—the first year at the cost of the contractor.

The cost of maintaining the asphalt pavements of Washington, D. C., is stated to vary from 1½ to 2 cents per square yard, per annum.

236. In Paris the asphaltic pavements cost about 40 cents per square yard per annum to maintain, including the charge for renewing $\frac{1}{15}$ part of the surface every year.

237. Mr. Elliot C. Clarke gives the following as the cost per

square yard per annum of Val de Travers compressed asphalt under an annual traffic tonnage of 100,000 tons per yard of width.

Interest on origiual cost	19.4 cents
Maintenance per square yard	7.2 "
Scavenging per square yard	0.8 "
Total	27.4 cents

Nothing is charged for renewal, as the annual sum for maintenance provides for the asphalt in perpetuity.

238. In Omaha, Neb., the cost of maintenance, after the expiration of the guarantee period, is 8 cents per square yard, under a ten years' contract.

239. In Berlin, the cost of maintenance for twenty years is fixed by contract at \$1.50 per square yard.

240. Foundation.—A solid unyielding foundation is indispensable with all asphaltic pavements, because asphalt of itself has no power of offering resistance to traffic; consequently, if the foundation is not thoroughly solid and unyielding the weight of the traffic will crush it, and the asphalt will give way in all directions and go to pieces. Two classes of foundation are used: (1) Hydraulic cement concrete; (2) Bituminous concrete.

241. Each class of concrete has its advantages and disadvantages: with cement concrete, the bond between the foundation and the wearing surface is not very great, hence it is very easy to strip off the surface in case repairs are necessary; but, on the other hand, the surface sometimes slips on the foundation, and under traffic rolls into waves and irregular surfaces, and sometimes cracks with sudden and great changes of temperature. A cement concrete foundation must be set and thoroughly dry before the asphalt is laid; the best asphalt laid in the most skilful manner on first-class but damp concrete will rapidly go to pieces. When the hot asphalt is applied to a damp surface the water is immediately sucked up and turned into steam, which tries to escape through the heated material; the result is that coherence is prevented, and, although the surface of the asphalt is smooth, the mass is really disintegrated from underneath by its bitter enemy, "water." As soon as the pavement is subjected to the action of traffic, the fissures formed by the steam appear on the surface, and the whole pavement quickly

falls to pieces. For the same reason asphalt should be laid only in dry weather.

242. With bituminous concrete the foundation and wearing surface are united into one mass and cannot be easily separated. Repairs are difficult, but waving and cracking are less frequent, and the bituminous concrete is less expensive.

243. **Trinidad Asphaltum.**—The source of this asphaltum is the so-called pitch "lake" in the island of Trinidad, W. I. The "lake" is a flat expanse of over 100 acres in extent, of a rough brownish material having an earthy appearance. Its surface is broken here and there with cracks and fissures, pools of water, and patches of soil. Its depth has not been accurately ascertained. Certain rude borings show it to have a depth on the sides of 18 feet and in the centre a depth of 78 feet. If these figures are correct, the deposit must contain several millions of tons of crude asphaltum. The deposit is said to lie upon a bed of sandy clay through which the asphaltum seems to rise.

244. The asphaltum is quarried by excavating with picks areas 30 or 40 feet square to a depth of 2 or 4 feet. As soon as this work ceases on one of these excavations the asphaltum begins to obliterate it, not by the walls closing in perceptibly, but by the bottom rising up, and in a few days no trace of the opening remains.

245. The deposit is situated about three miles from the shore of the island and about one hundred feet above the sea. The excavated material is loaded into carts and hauled to the shore. Here it is placed in baskets, which are carried by coolies wading through the surf to lighters, and from these lighters it is loaded on vessels. During the voyage the material unites into a solid mass, and has to be removed from the vessel by the use of picks and shovels.

246. The character of the material from different parts of the lake and from the old deposits between the lake and the shore is very different, the older deposits being much harder and drier, containing less of the oily constituents, and at times showing portions resembling coke. This difference in quality is distinguished in the trade by the terms "lake" or "live" asphalt, and "overflow" or "dead" asphalt. The overflow asphalt appears to be deficient in some of the qualities or constituents of the asphalt from the lake, which renders it defective when laid in the pavement of carriage-

ways, while in other situations, where vibration is small or entirely absent, the difference in quality is not so noticeable.

247. Preparation of Trinidad Asphaltum.—The crude asphaltum as unloaded from the vessel is a dull brownish-black earthy-looking substance containing much water and some earth and vegetable remains. It is heated in iron boilers, the most improved form of which are horizontal cylindrical double-return-flue boilers, so arranged with a system of firebrick flues that the direct heat from the fire first reaches the sides of the boiler, and then, passing through the flues in the upper half of the boiler, finally returns underneath the bottom of the stack. The boilers refine from 50 to 60 tons of crude asphaltum in about 100 hours. During the heating the temperature is raised to between 300° and 400° Fahr., the water is driven off, and the asphaltum brought to a liquid condition; much of the earthy matter settles to the bottom, and the organic or vegetable remains rise to the top. The liquid asphaltum is then drawn off as refined asphaltum.

The residue remaining in the boiler forms a considerable percentage of the whole crude material. It consists of the impurities of the crude mass, and frequently amounts to 12 per cent of the original weight. The greater this residue is the better the quality of the supernatant asphaltum.

248. "In the earlier part of the refining process large pools of water, contained in the crude material and liberated on its melting, collect on the surface. This water has proved of considerable interest from a chemical and geological point of view in its relation to the origin of bitumen. It has all the characteristics of a strong thermal water and contains over 2 per cent of salts in solution. It is acid in reaction, effervescing strongly with carbonates. It becomes oxidized on exposure to the air, and precipitates of iron, manganese, and silica are deposited. The distillate from the stills is strongly acid, and free hydrochloric, sulphuric, hydrosulphuric acids and other sulphur compounds have been determined in it. The gases evolved from the still contain so much hydrosulphuric acid that white paint in the neighborhood is turned quite black."

249. "The effect of this acid water cannot be a desirable one upon the bitumen, nor the presence of such a large proportion of salts, which in one of the large stills must amount to about a quarter of a ton of common salt and sodium sulphate. It is suggested

that this water be drawn off as much as possible, and the acidity of the remainder neutralized by the addition of carbonates during the refining process."

250. The refined asphaltum has a dull fracture, darker than the crude material, and a homogeneous appearance. It is very brittle at ordinary temperatures and possesses little cementitious value. To give it the necessary tenacity it is mixed, while at a temperature of about 325° Fahr., with from seventeen to twenty pounds per hundred of the residuum from the distillation of petroleum, a thick, heavy paraffine oil varying considerably in composition, according to the source of the petroleum and method of distillation.

The base of this residuum is paraffine—a substance so different from asphaltum, that when the two are brought together the result is a mixture rather than a chemical combination; and being of different specific gravities, there is a tendency to separate when allowed to stand for any considerable period without stirring. Thorough agitation is very necessary to produce an even product, which in summer, on cooling, can be easily indented with the fingers, and on slight warming drawn out in strings, and showing great tenacity. This is the asphalt cement used for paving. It must be prepared with great care, and it requires considerable experience to obtain a regular product of the proper consistency. A mistake in this regard is fatal to the life of the surface.

251. Mr. Clifford Richardson, inspector of asphalt and cements at Washington, D. C., says in his annual report that "formerly in oiling the refined asphalt a sufficient amount of residuum oil was emptied from barrels into the melted asphalt in the stills, and then agitated. The lack of uniformity in the character of the oil in different barrels made the result very uncertain, and with no opportunity for testing before use, and no definite means of determining its consistency, the results produced were extremely variable. At present each shipment of the oil is pumped into storage-tanks, where the entire lot is well mixed, and can be depended upon as uniform. While transferring in this way from barrels to tanks the character of the oil and the amount of water it contains can be determined."

Mr. Richardson has found that the flash-point, flowing-point, and character of the paraffines are the best indices of the nature of the oil. The best flashes at about 350 or 400 degrees Fahr., does not

flow above 60 degrees or below 32 degrees Fahr., and does not contain coarsely crystallizing paraffines when solid, but is rarely of a vaseline nature. From these characteristics it is possible to determine very nearly how much of any mixed tanks of oil to use in a still to produce a required penetration. This amount is pumped in after the refined asphalt has been cooled to about 325 degrees Fahr., after which agitation with a blower takes place for 10 or more hours. In this way a very regular material can be produced, varying according to the nature of the oil used. Its character is tested by means of the Bowen testing-machine, which consists of a lever about 17 inches long, containing a sharp cambric needle at one end, and loaded at the same end with a weight of 100 grains. The lever is connected with a spindle and dial through a steel rod and waxed cord. The rod and lever are held fixed at any point by means of a clip. The asphalt mixture is placed in such a position that its surface just touches the point of the needle, and then the clip being released for a second of time, the amount of penetration is registered on the dial. The temperature of the cement must be carefully observed. Originally Prof. Bowen selected 77 degrees as a proper temperature, and brought his cements to this degree by keeping them and his machine in a room kept warmed to this point.

Mr. Richardson has found it more simple and of universal application to use a tank of water at the standard temperature, in which the mixtures are immersed. Several penetration tests can then be made in a room of ordinary temperature before any change in the sample takes place. This modification permits of the use of the machine to great advantage at the works in following the oiling of asphalt. One has been employed at the yards of the Barber Company for some time for this purpose.

252. The oils employed during the year covered by the report were obtained from Lima, Scranton, and Baltimore, and have proved very variable in character, even from the same source. It seems impossible to expect a uniform supply, and the only course is to handle the different oils as well as the interpretation of the analysis and examination will allow.

253. The proportions of materials for the asphalt surfacing employed by the Cranford Paving Company and the Barber Asphalt Paving Company average as follows:

Weight of—	Cranford.		Barber.	
	Pounds.	Per cent.	Pounds.	Per cent.
Sand	584	75.0	637	74.3
Stone dust	54	6.9	60	7.0
Limestone dust	30	3.8	35	4.1
Asphalt cement	111	14.3	125	14.6

254. Analyses are made daily of selected samples of the surface material as it goes upon the street. There is, of course, some variation from load to load in the amount of bitumen, but this is very small. Out of 17 samples taken at different times on one day, only three showed deviations of more than 0.2 per cent from the average. Slightly more asphalt is used during the winter than in the summer.

255. Trinidad Asphaltum Pavements.—The wearing surface of these pavements, as laid in the United States, is composed of:

Asphalt cement	12 to 15	per cent
Sand	83 to 70	"
Pulverized carbonate of lime	5 to 15	"
	100 100	"

In order to make the pavement homogeneous, the proportion of asphaltic cement is varied according to the quality of the sand obtainable. The sand must be clean and free from clay. When suitable sand can be obtained the carbonate of lime is reduced or omitted entirely.

The sand and asphaltic cement are heated separately to about 300 degrees Fahr. The pulverized carbonate of lime, while cold, is mixed with the hot sand in the required proportions, and is then mixed with the asphaltic cement at the required temperature, in the proper proportions, and in a suitable apparatus, which will effect a perfect mixture.

The pavement mixture thus prepared is spread on the foundation in two coats. The first coat, called cushion-coat, contains from 2 to 4 per cent more asphalt cement than given above; it is laid to such a depth as will give a thickness of half an inch after being consolidated by the roller. The second coat, called surface-

coat, prepared according to the formula given above, is brought to the street at a temperature of about 250 degrees Fahr., and is spread on the cushion-coat by means of heated iron rakes, in such manner as to give a uniform and regular surface, and to such depth as will give after compression the required thickness of two or more inches. The surface is then compressed by rollers, a small quantity of hydraulic cement is scattered over the surface, and rolling continued until the roller ceases to make an impression on the surface.

256. A cubic yard of the prepared material weighs about 4500 pounds and will lay the following amount of wearing surface:

$2\frac{1}{4}$ inches thick	12 square yards
2 " "	18 " "
$1\frac{1}{2}$ " "	27 " "

257. One ton of the refined asphaltum makes about 2300 pounds of asphaltic cement, equal to about 3.4 cubic yards of surface material.

258. Extracts from the Reports of City Civil Engineers.—Washington, D. C. (Capt. Greene, 1885).—The Trinidad asphalt has been the standard pavement for the last seven years, about 600,000 square yards having been laid on a foundation of hydraulic concrete, and about 160,000 yards more on the stone foundations of the worn-out tar pavements. Its cost for the last three years has been about $2.25 per square yard. When made with skilled labor and laid under proper supervision it seems to answer all the requirements of a first-class pavement in this city. It is almost noiseless, not slippery, under ordinary conditions offers little resistance to traction, is easily repaired and cleaned, and is very durable. Large numbers of streets have been laid five, six, and seven years, and are in perfect order, although not a cent has been expended on them for repairs. On other streets mistakes have occasionally been made in the mixture, and defects have appeared which needed repairs. Nearly all these repairs have been made at the contractor's expense during his guarantee period; but as nearly as it can be ascertained the total expense both to contractors and the District for repairing asphalt pavements during the eight years since they were first laid has been about $30,000, or $3750 per year, so that the average annual expense for maintenance up to date has

been $\frac{9}{10}$ of one cent per yard per year. This is certainly a small expense for the luxury of smooth pavements, and much less than for any other pavement having the combined durability and smoothness of the asphalt.

259. *The French Asphalt Pavement,* made from the natural bituminous limestone of Switzerland, and similar in every respect to the asphalt pavements as laid in Paris, was tried here in 1873 and 1876, 31,388 yards having been laid on the following streets, viz.: Pennsylvania Avenue, between First and Sixth streets; I Street, betwen Thirteenth and Fifteenth streets; and Grant Place, between Ninth and Tenth streets. Experience has shown that this pavement is more slippery than the pavement of sand and Trinidad asphalt, and that it is not quite as durable. Its cost is nearly fifty per cent greater; for these reasons no more of it has been laid.

260. Buffalo, N. Y.—The streets paved with asphalt have stood the extreme changes of this climate without any serious defect, are giving satisfaction to our people, being healthful, easily kept clean, smooth, yet not slippery.

261. Omaha, Neb.—"Our temperature varies as much as 150 degrees Fahr., between the extremes of summer and winter. We are subject to rapid changes of temperature, which in the winter season occasionally are as high as 60 degrees in twenty-four hours. Douglass Street, which was paved in the fall of 1882 and spring of 1883, has experienced a range of temperature of from 120 degrees in the summer to 34 degrees below zero in the winter. . . . Our experience is very favorable to asphalt pavements on all grades ranging from 6 inches to 4 feet rise per 100 feet, and I am not sure but that as high as 5 or 6 feet per 100 feet may be favorably overcome. The asphalt pavement is not as cheap as wood, but, in my opinion, a preferable pavement upon permanently established and well-improved streets. It is not quite as easy for horses as wood, but more comfortable for those who ride, is more cleanly, and from a sanitary standpoint far superior."

262. Heads of Specifications for Standard Trinidad Asphaltum Pavements.

(1) *Preparation of Roadbed.*

(2) *Foundation.* (Hydraulic-cement or bituminous concrete.)

(3) *The Wearing Surface* will be composed of

(*a*) Refined Trinidad asphaltum.

(*b*) Heavy petroleum oil.

(*c*) Find sand containing not more than one per centum of hydrosilicate of alumina.

(*d*) Fine stone-dust.

(*e*) Fine powder of carbonate of lime.

(4) *Preparation of the Asphalt.*—The Trinidad asphaltum shall be refined, and as far as possible freed from foreign organic and animal matter and volatile oil, and brought to uniform standard of purity and gravity, containing not less than 60 per cent of bituminous matter soluble in bisulphide of carbon. The asphaltum must be refined under the direction and to the satisfaction of the engineer, and kettles will not be drawn lower than may be ordered by him.

The heavy petroleum oil shall be freed from all impurities and brought to a specific gravity of from 18 to 22 degrees Beaumé and a fire test of 250 degrees Fahrenheit.

From these two hydro carbons shall be manufactured an asphalt cement which shall have a fire test of 250 degrees Fahr., and at a temperature of 60 degrees Fahr. shall have a specific gravity of 1.19, said cement to be composed of 100 parts of pure asphalt and from 15 to 20 parts of heavy petroleum oil.

(5) *Manufacture of the Paving Material.*—The asphalt being prepared in the manner above described, the pavement mixture will be formed of the following materials, and in the proportions stated.

Asphaltic cement	from	12	to	15
Sand	"	83	"	70
Pulverized carbonate of lime	"	5	"	15

or

Asphaltic cement	from	13	to	16
Sand	"	63	"	58
Stone-dust	"	28	"	23
Pulverized carbonate of lime	"	3	"	5

The proportion of the materials will depend upon their character and the traffic on the street, and will be determined by the engineer. If the proportions of the mixture are varied in any manner from those directed to be used, the mixture will be condemned; and if already placed on the street, it will be removed and replaced by proper material, at the expense of the contractor.

The sand, stone-dust and asphaltic cement are to be heated separately to about 300 degrees Fahr. The pulverized carbonate of lime while cold shall be mixed with the hot sand and stone-dust in the required proportions, and then mixed with the asphaltic cement at the required temperature, and in the proper proportion, in a suitable apparatus, which will effect a perfect mixture. The proportions will be gauged daily in the presence of the inspectors.

(6) *Quality of the Materials.*—All the materials used, as well as the plant and method of manufacture, will be subject to the inspection and approval of the engineer. The degree of fineness, both of the sand, stone-dust, and powdered limestone, will be determined by testing with screens, as follows: The powdered carbonate of lime will be of such degree of fineness that 15 per cent by weight shall be an impalpable powder of limestone, and the whole of it shall pass a No. 26 screen. The sand will be of such size that more than 50 per cent of it will pass a No. 80 screen, and the whole of it shall pass a No. 20 screen. The stone-dust shall be the residue of granite or other approved stone, and shall pass a sieve of not more than 6 meshes to the inch.

(7) *Laying the Asphalt.* (Two-coat Pavements.)—The pavement mixture, prepared in the manner thus indicated, shall be laid on the foundation in two coats. The first coat, called cushion-coat, shall contain from 2 to 4 per cent more asphaltic cement than given above; it will be laid to such depth as will give a thickness of ½ inch after being consolidated by a roller. The second coat, called surface-coat, prepared as above specified, shall be laid on the cushion-coat; it shall be brought to the ground in carts at a temperature of about 250 degrees Fahr., and if the temperature of the air is less than 50 degrees iron carts with heating apparatus shall be used in order to maintain the proper temperature of the mixture; it shall then be carefully spread by means of hot iron rakes, in such manner as to give a uniform and regular grade, and to such depth that after having received its ultimate compression it will have a thickness of 2 inches. The surface then shall be compressed by hand rollers, after which a small amount of hydraulic cement shall be swept over it, and it then shall be thoroughly compressed by a steam roller weighing not less than 250 pounds to the inch run; the rolling to be continued for not less than five hours for every 1000 yards of surface.

(8) *Laying the Asphalt.* (One-coat Pavement.)—The pavement mixture, prepared in a manner thus indicated, will be laid on the foundation; it will be laid to such depth as will give a thickness of 2½ inches after being consolidated by rollers. It will be brought to the ground in carts, at a temperature of not less than 250 degrees Fahr. nor more than 310 degrees Fahr., and if the temperature of the air is less than 50 degrees the contractor must provide canvas covers for use in transit. It will then be carefully spread by means of hot iron rakes, in such manner as to give uniform and regular grade and to such depth that, after having received its ultimate compression of two fifths, it will have a net thickness of 2½ inches. This depth will be constantly tested by means of gauges furnished by the engineer. The surface will then be compressed by hand rollers, after which a small amount of hydraulic cement will be swept over it, and it will then be compressed by a steam roller weighing not less than 5 tons, to be followed by another steam roller weighing not less than 10 tons, the rolling being continued for not less than 10 hours for every 1000 yards of surface.

(9) In order to make the gutters entirely impervious to water, a width of 12 inches next the curb will be coated with hot pure asphalt and smoothed with hot smoothing-irons in order to saturate the pavement to a certain depth with an excess of asphalt; or if so directed by the engineer, the gutters will be formed with gutter-stones, granite blocks, or bricks, in accordance with the specifications for such work.

(10) *Laying Granite Blocks adjoining Railway Tracks.*—When asphalt pavement is laid in a street containing the tracks of a street railroad one row of selected granite paving-blocks will be laid next to the track, alternating as headers and stretchers toothing into the pavement. The foundation will extend to the depth of the bottom of the cross-ties, and will be similar in all respects to the foundation of the carriageway pavement, except as to the thickness of the base. If the foundation consists of bituminous concrete, the blocks will be laid directly upon and embedded in the binder while it is still in a hot and plastic condition. If the foundation consists of hydraulic-cement concrete, the base will be covered with a layer of fine sharp sand, washed and dried, 2 inches in thickness, and the blocks will be laid directly upon and embedded in the sand with close joints.

The top of the blocks will be even with the surface of the tread of the rail, which shall conform with the grade of the street. The blocks will be laid before the asphaltic wearing surface is laid upon the carriageway, and carefully rammed to a firm bed. Care will be taken to fit them well up against the stringers or web of the rail of the railroad. The space back of the blocks will be filled to the surface of the base for the carriageway pavement with the same material as is used for said base, well rammed.

Immediately after the wearing surface shall have been laid, clean, fine, hot gravel, not larger than one-half inch in any direction, will be poured into the joints of the blocks until they become nearly filled. There will then be poured into the joints, at a temperature of 300 degrees Fahr., paving cement made of No. 6 coal-tar distillate, until the joints are completely filled flush with the surface of the pavement. Additional fine hot gravel will then be poured along the joints, and will be consolidated by tapping with a light rammer. If found necessary additional paving cement will be poured between the blocks until the joints are thoroughly filled.

In measuring this work for payment, when standard size granite blocks are used, the area included between the outer edge of the rail and a line parallel to and six inches from rail will be taken as the area of granite-block pavement laid. Bids will be based on this rule. When so ordered, the block pavements will be extended to cover the entire area included between the rail and parallel to and 2 feet distant from said rail. In case the tracks are laid with a grooved girder rail, these headers and stretchers may be omitted if so ordered by the engineer, and the asphalt pavement laid close to the rail.

(11) The work of laying the asphalt shall not begin until the curbstones, crosswalks, catch-basins, manhole heads, etc., have been properly adjusted to the finished grade of the street, and permission to proceed has been received from the engineer.

(12) Interpretation of specifications.

(13) Omissions in specifications.

(14) Engineer defined.

(15) Contractor defined.

(16) Notice to contractors, how served.

(17) Preservation of engineer's marks, etc.

(18) Dismissal of incompetent persons.
(19) Quality of materials.
(20) Samples.
(21) Inspectors.
(22) Defective work, responsibility for.
(23) Measurements.
(24) Partial payments.
(25) Commencement of work.
(26) Time of completion.
(27) Forfeiture of contract.
(28) Damages for non-completion.
(29) Evidence of the payment of claims.
(30) Protection of persons and property.
(31) Indemnification for patent claims.
(32) Indemnity bond.
(33) Bond for faithful performance of work.
(34) Power to suspend work.
(35) Right to construct sewers, etc.
(36) Loss and damage.
(37) Old materials, disposal of.
(38) Cleaning up.
(39) Personal attention of contractor.
(40) Payment of workmen.
(41) Prices.
(42) Security retained for repairs.
(43) Payment when made, final acceptance.

263. Specifications for Asphalt Pavement on Bituminous Base.—Combination asphalt pavement on bituminous base will consist of a base 4 inches, a binder of 1½ inches, and a wearing surface of 1½ inches in thickness, when compacted.

The space over which the pavement is to be laid will be excavated to the depth of 7 inches below the top of the surface of the pavement when completed. Any objectionable or unsuitable material below the bed must be removed, and the space filled exactly parallel to the surface of the new pavement when completed; and the entire roadbed will be thoroughly rolled with a heavy steam-roller weighing not less than 5 tons. Upon the foundation will be laid the base and binder, 5½ inches in thickness, in the following manner:

Base.—The base will be composed of clean broken stone that will pass through a 3-inch ring, well rammed and rolled with a steam-roller weighing not less than 5 tons, to a depth of 4 inches. The rolling will be continued until the stone ceases to creep before the roller, and until it is evident that the final compression has been reached. It will be thoroughly coated with No. 4½ coal-tar paving cement in the proportion of about one gallon to the square yard of base.

Binder.—The second or binder course will be composed of clean broken stone, thoroughly screened, not exceeding 1 inch in the largest dimension, and No. 4 coal-tar paving-cement. The stone will be heated to a temperature between 230 and 250 degrees Fahr., by passing through revolving heaters, and thoroughly mixed by machinery with the paving-cement in about the proportion of one gallon of No. 4 tar to one cubic foot of stone. It will be hauled upon the work, spread upon the base course to such thickness that when compacted it will be 1½ inches thick, and immediately rammed and rolled with hand and steam rollers while in a hot plastic condition.

Wearing Surface.—The wearing surface will be 1½ inches thick when compacted, and will conform in all other respects to the wearing surfaces as prescribed for the standard asphalt pavement, as described in these specifications.

The pavement so constructed must be a solid mass, 7 inches thick, and must be thoroughly rolled and cross-rolled until it has become hard and solid.

Gutters, wherever directed, will be formed of granite-block or brick, of such width as may be directed, laid upon a hydraulic base of not less than 4 inches in thickness, in accordance with the specifications for granite-block pavement and for brick gutters.

264. Specifications for Asphalt Pavement on Hydraulic Base.—The asphalt pavement on hydraulic base will be 7 inches in thickness, consisting of a base composed of 4 inches of hydraulic concrete and 2 inches of binder, 1½ inches when compacted, and a wearing surface of standard asphalt, 2½ inches in thickness, or 1½ inches when compacted.

Binder Course.—The binder course will conform in all respects to the binder course for the asphalt pavement on bituminious base, and will be 1½ inches in thickness when compacted.

Wearing Surface.—The wearing surface will be $1\frac{1}{2}$ inches thick when compacted, and will conform in all other respects to the wearing surfaces as prescribed for the standard asphalt-pavement.

265. Maintenance of Asphalt Pavements under Contract.—The contractors will furnish all the labor and materials necessary to make repairs and renewals required to preserve the surface in a perfect state, true to the profile, without humps or depressions, even if the dilapidations are the result of accidental causes, as sinking of the subsoil, etc., except only the digging of trenches. The contractor must renew all places where the surface is cracked, split, depressed, swelled, or in any way perforated, where it matches unevenly with manhole heads and other street fixtures, etc., and especially where sunken near trenches.

Where the foundation is defective, it shall be removed and replaced with good material. Defective spots must be carefully cut out with a sharp tool, and at least 2 feet larger in every direction than the defective place; the sides must be cut on straight lines; there must be a perfect union of the old and new material, and the surface must show no irregularities.

On September 1st, or sooner in case of bad weather, a general examination will be made with the contractor, who must immediately begin repairs on doubtful surfaces, not likely to endure through the winter. In rainy weather the bottoms of patches must be sponged and dried as carefully as possible with fine hot ashes, and then be well brushed. Special care must be taken to clean all sand, powder, etc., from the bottom of patches.

During bad weather no repairs shall be made to the asphalt, unless expressly authorized by the engineer. Patches made during winter are to be considered as only temporary, and must be replaced by the 15th of May.

The contractor is absolutely forbidden to use pebbles for filling holes in the asphalt. When the contractor fails to make the necessary repairs, and the administration, exceptionally and in default of other available means, fills the holes with broken stone or other material, the contractor must pay for the work and materials, and cannot claim damages for injury to the pavement caused by such materials.

In winter, holes in the foundation may be filled with a mixture of 3 parts by volume of pebbles to 1 part of hot asphalt; but this

provisional filling must be removed as soon as possible and replaced in the standard manner.

The contractor will be paid for repairs to all trenches opened in the street. He can, however, make no claim for settlement or any other injury at these places, and must maintain the pavement there in the same condition as elsewhere.

To secure a perfect welding at the edges of the asphalt, a width of 2 inches greater in every direction than the trench will be paid for.

To provide for settlement of the earth in the trenches, the contractor may maintain the area occupied by the trench, during a period of eight days, with broken stone or gravel, well rammed, sprinkled, swept, and maintained, so as to prevent injury to horses. If after eight days final repairs are still impossible, the contractor must at his own expense make a provisional surface of bituminous concrete, which will be removed for final repairs.

If for any reason it becomes necessary to tear up asphalt pavements, it shall be done as follows: It will be cut in as straight lines as possible with sharp chisels, and when torn up must on no account pull up with it any of the adjacent material.

Then the concrete is to be cut by sharp chisels in lines about 3 inches from the edge of the asphalt, which may be broken into pieces and laid aside.

In removing the earth from the excavation, care must be taken that no portion of the concrete is undermined.

265a. The "Bermudez" Asphalt, recently introduced for paving purposes, is obtained from a lake or deposit which covers an area of several hundred acres in the state of Bermudez, Venezuela, S. A.

The purity and quality are said to be exceedingly high; the following analysis is given by Prof. E. J. De Smedt:

Bitumen soluble in CS_2	97.86 per cent
Organic and inorganic matter (impurities)	2.14 "
	100.00 per cent

The following are some of the characteristics of this asphalt:

At 60° F. compressible; at 70° F. viscous and malleable; at 100° F. flowing, and can be stretched in hair-like threads; at 189° F. melts; at 400° F. gives no flash.

The paving-cement is manufactured by adding 15 lbs. of residuum oil, 20 Baumé at 60° F., to each 100 lbs. of refined asphalt. This 100 lbs. of refined asphalt yields 97.06 lbs. of pure bitumen; consequently $13\frac{3}{10}$ per cent of oil is added to the pure bitumen.

The asphalt is melted at from 250° to 300° F. The oil is then added and thoroughly mixed with the melted asphalt.

The pavement mixture is composed of the following materials and in the proportions stated:

Asphaltic cement	9 to	10	parts
Pulverized carbonate of lime	20 "	30	"
Fine clean sand	71 "	60	"
	100	100	

The sand and carbonate of lime are mixed and heated to from 250° to 300° F. The asphaltic cement is heated separately to from 225° to 250° F. The materials so heated are mixed in a suitable mixing apparatus, and the mixture while at a temperature not below 200° F. is spread upon the foundation in two coats, the lower or cushion coat being one-half inch thick after compression, and the second or wearing coat being two inches thick after final compression with a roller weighing not less than 250 lbs. per inch run. A small amount of hydraulic cement is swept over the surface before the application of the roller.

It is claimed that pavements made from this asphalt do not rot in contact with water.

One square yard of pavement $2\frac{1}{2}$ inches thick weighs 250 lbs.

266. European Asphalt Pavements.—In Paris two kinds of asphalt pavement are employed. First, *asphalt coulé*, made from natural rock asphalt to which is added sufficient bitumen to make the total 15 to 18 per cent of bitumen. The mass is heated for about six hours so as to make a thorough mixture. The ground having been graded, sprinkled and thoroughly rammed or rolled, a bed of hydraulic-cement concrete from 4 to 6 inches thick is laid, and after this is set and well dried the asphalt mixture is spread and surfaced by a wooden float. The thickness of the asphalt is about $1\frac{1}{4}$ inches, and it is usually applied in two layers. This covering will not soften at a temperature of 140 degrees Fahr.

267. The second kind of asphalt covering is *asphalt comprimé*, or compressed asphalt. In this the natural rock alone is used. It

comes from Val de Travers in Switzerland, Seyssel in France, and other localities, and consists of carbonate of lime impregnated with bitumen. The color is a dark (almost black) chocolate-brown. When cold the rock breaks easily, with an irregular fracture and without definite cleavage. Its grain should be regular and homogeneous; the finer the grain the better. When exposed to the atmosphere the bituminous rock gradually assumes a gray tint, by reason of the bitumen evaporating from the surface, leaving a thin film of limestone behind.

268. The following is a test for bituminous rock given by Mr. Deland in a paper he read before the Institution of Civil Engineers in the year 1880. "A specimen of the rock, freed from all extraneous matter, having been pulverized as finely as possible, should be dissolved in sulphurate of carbon, turpentine, ether, or benzine, placed in a glass vessel and stirred with a glass rod. A dark solution will result from which will be precipitated the limestone. The solution of bitumen should then be poured off. The dissolvent speedily evaporates, leaving the constituent parts of the bitumen, each of which should be weighed so as to determine the exact proportion. The bitumen should be heated in a lead bath and tested with a porcelain or Baumé thermometer to 428 degrees Fahr. There will be little loss by evaporation if the bitumen is good, but if bituminous oil is present the loss will be considerable. Gritted mastic should be heated to 450 degrees Fahr. The limestone should be next examined. If the powder is white and soft to the touch, it is a good component part of asphalt; but if rough and dirty, on being tested with reagents it will be found to contain iron pyrites, silicates, clay, etc. Some bituminous rocks are of a spongy or hygrometrical nature; thus, as an analysis which merely gives so much bitumen and so much limestone may mislead, it is necessary to know the quality of the limestone and of the bitumen."

The European bituminous limestone appears like a fine-grained rock, friable in summer, hard in winter. When heated to 50 or 60 degrees (centigrade) it can be crushed between the fingers, and if exposed for several hours to a fierce sun it crumbles into unctuous brown powder. Examined under the microscope it is found to consist of minute calcareous grains, each covered with a thin film of bitumen which causes them to adhere together. If a small portion is heated, the cementing bitumen is melted and releases the

solid particles from a loose heap of a deep chocolate color. If this powder is raised to 175 or 212 degrees Fahr. and rapidly compressed in a mould, it will regain, in cooling, its original consistency in the new form. And the process may be indefinitely repeated, no change being produced by melting, followed by compression and cooling.

269. The best material used by the "Compagnie Generale des Asphaltes de France" comes from the Pyrimont mines of the Seyssel region in the Department of Haute Savoie and Litin, France. The workings are in great part subterranean and the deposit lies in eight superimposed beds separated by beds of white limestone. One of these bituminous beds lies about 100 feet above the level of the Rhone and has a thickness of 23 feet; it is the largest of all known beds of this material. The galleries now driven aggregate about seven miles in length.

270. The rock is extracted in a temperature ranging from 53 to 55 degrees Fahr., and it is relatively hard. This desirable quality can be increased by taking it outside during the winter, but it should not even then be exposed to the sun. Dynamite or gunpowder is used in extracting it, the latter being used when the mass is compact, dry, and without fissures. As the rock is to a certain degree plastic, it compresses easily and does not work well with the more violent and quick explosives. On the other hand, dynamite is effectively used in the wetter parts of the mine and in places where fissures would permit the slower-acting gases from gunpowder to escape without efficient work.

The blocks of bituminous rock are removed outside by rail and as few blocks as possible are piled upon one car, to avoid crushing under the effect of the heat of the sun. This crushing is undesirable for two reasons: first, there is more waste in the transport and handling; and secondly, if rain falls upon a pulverized mass, it absorbs water rapidly and becomes exceedingly difficult to treat.

271. The operations preliminary to the application of the bituminous rock to the street surface are: (1) The extraction and (2) the crushing of the rock. (3) The heating of the powder. (4) Transporting the heated powder to the street. (5) Spreading it while warm. (6) Ramming. (7) Rolling.

272. The quarried blocks of mineral are crushed between toothed cylinders, revolving at unequal speeds, which reduce it to

pieces of the average size of eggs. These are pulverized in "Carr" machines, which run about 600 revolutions per minute, and deliver it as powder, which is sifted to uniform extreme fineness. This powder is heated in an apparatus resembling a "coffee-roaster;" the revolving cylinder is about 6½ feet in diameter and the same in length; the exterior envelope carries a chimney, disposed in such fashion that the heated air from the furnace passes all around the cylinder. The furnace itself is movable and placed immediately below the cylinder, and rests on a railway so that it may be run out of the way. The moving cylinder is mounted upon an axle and supported on journals in the enveloping cylinder, which rests upon four stout legs.

273. The powder is put into the roaster by means of a hopper placed opposite a central hole forming an annular space around the axle. The powder falls into the cylinder, which is moving very slowly; the cylinder is provided with interior blades arranged in a spiral, by which the contents are lifted up to the top and fall in a shower through the hot air in the cylinder, until it is thoroughly warmed both by this action and by contact with the hot sides of the cylinder. As the movement of the cylinder is perfectly regular, the powder remains on the blades only a determinable time, and the entire mass has imparted to it a uniform temperature. The apparatus used on the work of the city of Paris heat, to a temperature of about 300 degrees Fahr., about 3960 pounds of powder in 15 minutes.

When the powder is sufficiently heated the furnace is run out from under it, and is replaced by the special wagon used for transporting the warm powder to the place of use, into which the powder falls after opening a gate in the side of the cylinder.

274. Asphaltum is a bad conductor of heat, and this negative quality much simplifies the difficulties of its preparation, and permits the material to be heated at central stations and conveyed a considerable distance before it will fall appreciably in temperature; in fact, the powder loaded into sheet-iron carts with double sides and cover may be carried from 1¼ to 9⅓ miles from the place of heating to the place of use without losing on the way more than 35 or 40 degrees Fahr. of its mean temperature.

275. The hot material is emptied out on the concrete foundation, spread by hot rakes in a layer of sufficient thickness to allow

for compression to the exact finished surface and required thickness, viz., about 3 inches for a 2-inch coat.

The surface, and consequently the thickness, is regulated by a wooden straight-edge bearing on parallel guides set at the required height in the surface of the concrete.

276. The ramming is done by round cast-iron rams, 6 to 8 inches in diameter, which are used by fifteen or twenty men, marching side by side and vigorously ramming the asphalt while it is yet hot. After a few minutes a roller drawn by two men and heated by an internal furnace gives what is called the "primary compression," the normal compression being effected under the traffic by the carriage-wheels. During the rolling a small quantity of hydraulic cement is strewn over the surface. The rolling is continued until the asphalt is cold.

The bituminous limestone to form a good roadway pavement should contain from 9 to 10 per cent of bitumen, and be non-evaporative at 428° Fahr. Limestones containing much more than 10 per cent of bitumen become soft and wavy in summer; those containing much less have not sufficient binding power to sustain heavy traffic.

277. Bituminous Limestone Pavements in the United States. —About 55,000 square yards of bituminous limestone pavement were laid in Washington, D. C., during 1876 and 1887, and about 3000 square yards in New York in 1883 or 1884; nearly all of this was subsequently taken up and replaced by Trinidad asphalt. In 1887 about 10,000 square yards were laid in Rochester, N. Y.; in 1888 about 20,000 square yards in St. Augustine, Florida; and in 1890 40,000 square yards in New York City. The total amount of bituminous limestone pavements now in use in the United States is estimated at 75,000 square yards.

These pavements are composed of a mixture of about three parts of bituminous limestone rock from Ragusa, Sicily, and one part of a similar rock from Vorwohle, Germany; the latter is a harder rock and contains less bitumen than the Sicilian.

The paving mixture contains from 10 to 12 per cent of bitumen, and is prepared by pulverizing the mixed rock and heating it to a temperature of about 160° Fahr. The heated powder is laid and compressed in the manner described under European Asphalt Pavements.

278. Coal-tar Pavements.—The wearing surface of the earlier pavements was made in various ways, according to the patent, but consisted essentially of small gravel, sand, and stone-dust, cemented by a product of coal-tar. In the later pavements of this variety a certain proportion of bitumen is mixed with the tar, and with beneficial results.

Wherever laid in the United States, coal-tar pavements, as a rule, have given little satisfaction, their failure being due to the presence of volatile oils in the tar, which on exposure to atmospheric influence slowly oxidize and become inert, thus destroying the cementing qualities of the tar. If these oils are removed before the tar is used the resulting material is brittle, and soon crumbles to pieces after being laid. Coal-tar is also very sensitive to heat: in summer it is soft, in winter brittle. On account of these defects, the use of coal-tar alone, as a cementing material for pavements, has been almost entirely abandoned.

279. Coal-tar and Asphalt.—To overcome the defects of coal-tar when used alone, the practice has arisen of mixing the gas tars with bitumen, and this has been successful in proportion to the amount of the bitumen used. The most successful pavement of this character is that known as the "Vulcanite." This pavement is prepared as follows:

280. Filbert Vulcanite Asphalt Pavement as laid by the National Vulcanite Company of New Jersey.—The pavement is 8½ inches in thickness, formed as follows: The wearing surface 1½ inches when compacted, and a bituminous base and binder 7 inches in depth.

The base is composed of stone broken to pass through a 3-inch ring. It is spread on the earth surface, previously graded to receive it, to a depth of 5 inches, these consolidated with a steam roller, after which it is covered with a hot paving-cement composed of No. 4 tar distillate in the proportion of about one gallon to the square yard of pavement.

The second or binder course is composed of stone broken to pass through a 1½-inch ring,—the stone being thoroughly cleansed and screened,—and No. 4 tar distillate. The stone is heated by passing through revolving heaters, and is thoroughly mixed by machinery with the distillate in the proportion of one gallon of distillate to one cubic foot of stone.

The binder is spread upon the base to a depth of two inches, and is immediately rammed and rolled with hand and steam rollers while hot and in a plastic condition.

The wearing surface, 1½ inches thick, is made of paving-cement, composed of 25 per cent of asphalt and 75 per cent of tar distillate, and clean sharp sand and stone pulverized to pass through a ¼-inch ring in the proportion of two parts of sand to one part of stone.

To 21 cubic feet of the above ingredients are added one peck of hydraulic cement, one quart of flour of sulphur, and two quarts of air-slaked lime. To this mixture is added 320 pounds of paving-cement.

The materials above described are heated to about 250 degrees Fahr.—the paving cement in kettles, the sand, stone, etc., in revolving heaters—then thoroughly mixed by machinery, carried to the street, and spread on the binder course to a depth of two inches. While hot and plastic it is rolled with a steam roller, hydraulic cement being dusted over the surface. The rolling is continued until the roller ceases to leave an impression on the surface.

281. Advantages of Coal-tar and Asphalt or Distillate Pavement.

(1) It is cheap.

(2) Its surface is more granular and less slippery than asphalt.

(3) The binder binds the base and wearing surface firmly together and eliminates to a great extent the faults of weather cracks and wave-surfaces.

(4) It can be laid from curb to curb, as it will not "rot" in the gutters as does the asphalt.

(5) Pavements constructed of carefully selected and combined materials and properly laid will cost but little, if any, more than the asphalt for maintenance.

282. Defects of Coal-tar and Asphalt Pavement.

(1) The wearing surface consists of 75 per cent of coal-tar, which material can rarely be obtained of uniform quality.

(2) The wearing surface, being only 1½ inches thick, requires renewal at frequent intervals.

(3) The pavement is not so pleasing to the eye as asphalt in color.

(4) The use of the bituminous base gives rise to many perplexing problems in the grade of the streets on which it is used, due to the fact that the base, the binder, and the wearing surface co-

alesce so as to form a solid mass. The wear ont he surface is never quite uniform; and when the binder or base becomes exposed on the most travelled part of the street, the pavement near the gutter may be worn but slightly. To resurface properly, the remnants of the old surface should be removed, and the new surface laid directly upon the binder. It is, however, impracticable to strip a coal-tar surface. It may be broken by the pick and bar, but it breaks as readily in the base or binder as at the original line of demarcation. In fact, there is no such line. The practice is to cut out what may be necessary near the curb and put a new surface on the roadway as it stands. The result is to raise the level of the roadway at every resurfacing, or, if the original level at the curb be maintained by the method of cutting out as stated, to increase the crown of the street; but as such pavements will not, as a rule, require resurfacing at more frequent intervals than every fifteen years, and as the surfacing should not raise the level more than one-half inch, the upward growth will not exceed $3\frac{1}{2}$ inches per century.

283. Asphalt and Coal-tar or Distillate Pavements in Washington, D. C. (Extract from the Report of Capt. E. Griffin, United States Engineers, Assistant to the Engineer Commissioners, for the year ending June 30, 1887.)—During the year 1886–1887 six per cent of the new pavements laid was sheet coal-tar distillate. As this is the first year since the organization of the present form of District government that coal-tar distillate pavements have been laid in the streets of Washington, a few words in this connection will not be inappropriate. Previous to 1878, 745,305 square yards of coal-tar pavements of various kinds were laid at prices ranging from \$1.74 to \$3.70 per square yard. Many of these pavements proved unreliable, either through inherent defects in the materials used or faulty methods of mixing and laying. Some went to pieces in a few years, and others deteriorated so rapidly as to soon place the annual cost of maintenance at excessively high figures. Of the so-called Evans pavement 190,663 square yards were laid, mostly in 1873. When only two years old nearly all these pavements were resurfaced at an average cost of \$1.09 per square yard.

284. As late as 1877 Lieutenant Hoxie estimated twenty cents per yard per annum as the cost of maintaining coal-tar pavements.

285. The average annual expenditure for maintenance of coal-tar pavements for the fifteen years ending June 1, 1886, has been $7\frac{2}{10}$

cents per square yard. Of the Evans pavement, 157,324 square yards were resurfaced by Scharf within two years after being laid, and virtually became Scharf pavements. Considering them as such, the mean average annual expenditure for maintenance was 5$\frac{1}{2}$ cents per square yard. For the first five years the annual average was 3$\frac{7}{10}$ cents; for the second five years, 6 cents; for the last five years, 6$\frac{6}{10}$ cents.

286. "That a durable coal-tar pavement can be laid is proven by the fact that the 158,595 square yards of vulcanite pavements have only averaged 2$\frac{9}{10}$ cents per square yard per annum for fourteen years' maintenance, the average being $\frac{3}{10}$ cents per yard for the first five years, 4$\frac{2}{10}$ cents for the second five years, and 4 cents for the last four years.

287. The return to the coal-tar distillate pavements was virtually forced upon the commissioners by the clause in the appropriation act for 1886–7 which "provided" that under this act no contract shall be made for making or repairing concrete or asphalt pavements at a higher price than $2.00 per square yard for a quality equal to the best laid in the District prior to July 1, 1886, and with same depth of base.

288. No bids were received for asphalt pavements in response to proposals advertised for under this act, so a return to distillate pavements was made.

289. In 1888 bids for a modified asphalt pavement were received, and contracts have been made to lay a large proportion of the streets with it during the present year. This modified asphalt pavement consists of a 4-inch bituminous base, 1$\frac{1}{2}$ inch binder course, with a wearing surface of 1$\frac{1}{2}$ inches of Trinidad asphalt instead of 1$\frac{1}{2}$ inches of coal-tar distillate composition.

290. "Another modification of the standard asphalt pavement was laid in Washington last year. This consists of a base of 4 inches of hydraulic concrete, 1$\frac{1}{2}$ inches of bituminous binder, and 1$\frac{1}{2}$ inches of asphalt wearing surface-coat. This is in every respect a most excellent pavement, and more of it would be laid, only the contractors refuse to lay it for less than $2.10 per square yard, and as the law prohibits the payment of more than $2.00 its use had to be discontinued." (Report of Capt. T. W. Symons, United States Engineers, Assistant to the Engineer Commissioners of the District of Columbia in 1889.)

291. Specifications for Coal-tar Distillate Pavement.—Coal-tar distillate pavement will consist of a base and binder of 4½ inches in depth when compacted, and a wearing surface of 1½ inches in thickness when compacted. The space over which the pavement is to be laid will be excavated to the depth of 6 inches below the top of the surface of the pavement when completed. Any objectionable or unsuitable material below the bed must be removed and the spaces filled with clean gravel or sand well rammed. The bed will then be trimmed so as to be exactly parallel to the surface of the new pavement when completed, and the entire roadbed will be thoroughly rolled with a heavy steam roller. Upon this foundation will be laid the base and binder, 4½ inches in thickness, in the following manner:

Base.—The base will be composed of clean broken stone that will pass through a 3-inch ring, well rammed and rolled with a steam roller to a depth of 4 inches, and thoroughly coated with No. 1½ coal-tar paving-cement in the proportion of about 1 gallon to the square yard of base.

Binder.—The second or binder course will be composed of clean broken stone, thoroughly screened, not exceeding 1½ inches in the largest dimension, and No. 4 coal-tar paving-cement. The stone will be heated to a temperature between 230 and 250 degrees Fahr., by passing through revolving heaters and thoroughly mixed by machinery, with the paving-cement in about the proportion of 1 gallon of No. 4 tar to 1 cubic foot of stone. It will be hauled upon the work, spread upon the base course at least 2 inches thick, and immediately rammed and rolled with hand and steam rollers while in a hot plastic condition.

Wearing Surface.—The wearing surface will be composed of the following materials in the given proportions:

	Per cent.
Clean sharp sand	63 to 58
Broken stone or rock-dust	28 to 23
Paving-cement	13 to 15
Hydraulic cement	0.9
Slaked lime	0.15
Flour of sulphur	0.1

The sand shall be clean, sharp river sand, free from clay, and of such size that not more than 20 per cent shall be retained upon

a sieve of twenty meshes to the inch and not more than five per cent shall pass through a sieve of 70 meshes to the inch, about 60 per cent to be coarser than 40 meshes to the inch. The broken stone or stone-dust shall be the residue from the crushing of stone from the base and binder which passes a sieve of not more than 6 meshes to the inch.

The paving-cement shall be composed of fine Trinidad asphalt, twenty-five to thirty parts; No. 4 coal-tar paving-cement, seventy-five to seventy parts. The refined asphalt must contain at least 60 per cent of pure bituminous matter, soluble in carbon bisulphide. The No. 4 coal-tar paving-cement must correspond to a standard to be furnished by the engineer, and be free from excess of sooty matter, naphthaline and creosote oils. The hydraulic cement, lime, and sulphur must be of the best commercial quality.

The materials for the wearing surface will be heated to not over 26 degrees Fahr., the paving-cement in kettles, the sand and stone-dust in revolving heaters. To the latter the hydraulic cement, lime, and sulphur will be added cold in the sand-box before going to the mixer. They will be thoroughly mixed by approved machinery, and the mixture carried upon the work, where it will be spread upon the binder course 2 inches thick with hot iron rakes and other suitable appliances, and immediately compacted with hot tamping-irons and hand and steam rollers, while in a hot and plastic state. In spreading the material the joints are to be diagonal to the line of the street. The surface will be finished with a dusting of dry hydraulic cement rolled in. In cool weather or when ordered the carts carrying the mixture are to be protected with canvas covers.

The pavement so constructed must be a solid mass 6 inches thick, and must be thoroughly rolled and cross-rolled until it has become hard and solid. The relative proportions of the component materials will be changed upon the order of the engineer, as occasion shall require.

All materials, as well as the plant and methods of manufacture, will be subject to the inspection and approval of the engineer.

The degree of fineness, both of sand, stone-dust, and powdered limestone, will be determined by testing with screens as follows: The powdered carbonate of lime will be of such degree of fineness that 16 per cent of weight shall be an impalpable powder of limestone, and the whole of it shall pass a No. 26 screen. The sand will be

of such size that no more than 50 per cent of it will pass a No. 80 screen, and the whole of it shall pass a No. 20 screen. The broken stone or stone-dust shall be the residue from the crushing of stone from the base and binder which passes a sieve of not more than 6 meshes to the inch.

Gutters, wherever directed, will be granite-block or brick, of such width as may be directed, laid upon a hydraulic base of not less than 4 inches in thickness, in accordance with the specifications for granite-block pavement or brick gutters.

292. Asphalt-block Pavements. — These blocks are made of crushed limestone, in size from $\frac{1}{4}$ inch to dust, mixed with 10 per cent of asphaltic cement. As the mixture leaves the mixing apparatus it passes into a press not unlike a brick-machine, and is there moulded and compressed into blocks $4 \times 5 \times 12$ inches and $6 \times 8 \times 2\frac{1}{2}$ inches in size; the larger blocks weigh 22 lbs., and the smaller 14 lbs. These blocks are cooled, and can than be handled at any ordinary temperatures. They are laid on the street in the same manner as stone-blocks, to form a pavement. They have the advantage over any monolithic or "sheet" pavement of being made at a factory, whence they can be transported to the point where required, and laid by ordinary paviors without the aid of skilled labor; whereas sheet pavements require special machinery and skilled labor in each city where they are laid. The asphaltic blocks are also much smoother and less noisy than stone-block pavements, and they are practically water-proof, because the joints are so narrow, that under the sun's heat and the traffic the asphalt cements the blocks together.

293. It has been found impossible to use sand in the manufacture of these blocks, as it cuts the moulds; hence limestone is used to form the body of the block, and this wears rapidly under traffic.

On residence streets, however, where the traffic is light, they have given great satisfaction, and more than 1,500,000 square yards of them have been laid during the last twelve years.

294. Asphalt-block Pavement in Washington, D. C.—Quite a large amount of this pavement was laid in the year 1888–9.

295. Asphalt blocks do not make a suitable pavement for narrow, well-travelled streets, for the general surface of a street containing railway tracks or for streets of heavy traffic. Whenever laid

on such streets, they have heretofore failed to show the requisite endurance. They are only recommended for residence streets and streets of light traffic. In such locations they make an excellent pavement, smooth, durable, clean, healthy, and pleasing in appearance.

296. Specifications for Laying Compressed-asphalt Blocks.— Upon the soil-bed, previously compacted by rolling and ramming, a layer of bank gravel, screened from all pebbles measuring more than one and one-half ($1\frac{1}{2}$) inches in their largest dimensions, will be laid of such depth as to give five (5) inches in thickness when compacted by rolling and ramming. Upon the gravel will be spread a layer of fine sharp sand two (2) inches in thickness, to serve as a bed for the blocks, which will be laid directly upon and embedded in it with close joints. Special care will be observed to make the surface of the sand exactly parallel to the surface of the pavement when completed. The blocks shall be laid by the pavers standing or kneeling upon the blocks already laid, and not upon the bed of sand.

The blocks shall be laid with their length at right angles to the axis of the street; each course will be formed with blocks of a uniform width and depth. The blocks shall be so laid that all longitudinal joints shall be broken by a lap of at least four (4) inches. Each course of blocks will be driven against the course preceding it by a heavy wooden maul, in order to make the lateral joints as tight as possible. The longitudinal joints will be closed by pressing on a lever inserted at the end of the course adjoining the curb, and keying with a block cut to the required size. When laid, the blocks will be immediately covered with clean, fine sand entirely free from loam or earthy matter, perfectly dry, and screened through a screen having 20 meshes to the inch. The blocks will then be rammed by placing an iron plate, 20 inches by 8 inches, and 1 inch thick, over four blocks, and striking on the plate with a rammer weighing not less than 45 lbs. The ramming will be continued until the blocks reach a firm, unyielding bed and present a uniform surface, with the required grade and crown. Any lack of uniformity in the surface must be corrected by taking up the blocks, increasing the sand bedding, and relaying them. When the ramming is completed, a sufficient amount of fine, dry sand, as

above described, will be spread over the surface and swept into the joints.

296a. The cost of construction and maintenance is less than that of the standard asphalt. The blocks cost about $60 per 1000 or $1.56 per square yard, f. o. b. at the factory. Sand-rubbed blocks cost about $70 per 1000.

TABLE XXXVI.

EXTENT AND COST OF ASPHALT-BLOCK PAVEMENTS IN SOME OF THE PRINCIPAL CITIES OF THE UNITED STATES IN 1890.

Cities.	Extent. Miles.	Cost of Construction per square yard.
Philadelphia, Pa.	18.80	
Washington, D. C.	10.10	$2.00
Camden, N. J.	5.86	2.00
Chicago, Ill.	4.11	2.00
Trenton, N. J.	2.50	2.50
Schenectady, N. Y.	0.75	

297. American Bituminous-rock Pavements.—Beds of sandstone rock impregnated with bitumen are found in many places in the United States, but it is only within the last few years that it has come into use as a paving material. San Francisco, Los Angeles, and other cities now have several miles of this pavement.

298. The rock is quarried, broken into fragments, heated, and while hot taken to the street and compressed by rolling and tamping.

299. The reports concerning the durability of these pavements is conflicting. A claim is made that pavements made of this material 15 years ago and used under heavy traffic have recently been removed and found to have lost very little either in weight or thickness. On the other hand, it is claimed that these pavements are soft; that wheels and horses sink into them quite deeply, but these marks appear to be more or less obliterated by the next passing vehicle.

The granular nature of these pavements renders them less slippery than the ordinary asphalt pavements. They also possess the quality of resisting disintegration by moisture. It is also claimed that these pavements stand equally well the high tem-

perature of the interior cities and the cold, damp atmosphere of the coast.

300. Cost of Construction.—The cost of construction in the West is less than that of the standard asphalt, the average being about $2.50 per square yard, including a 6-inch concrete base. In the Eastern cities there is but little difference in their cost.

301. Cost of Maintenance—As none of these pavements has been laid on a large scale for longer than three years, nothing can be said as to their cost for maintenance.

302. One ton of the bituminous rock will form 10 square yards of pavement 2 inches thick.

303. Specifications for Bituminous-rock Pavements.—The manner of laying the bituminous rock is left to the contractor, except in the following particulars:

The bituminous rock used for the paving must contain not less than 7 nor more than 13 per cent of its weight of bitumen.

The powdered rock shall be prepared at a uniform temperature in suitable boilers.

Ten days before the award of contracts bidders must deposit in the office of the engineer samples of the bituminous rock which they propose to use. Each sample shall bear the bidder's name and the name of the place where obtained. All materials used must conform to the samples so deposited. If other material is wished to be used, samples of them must be deposited and accepted by the engineer.

The asphalt covering, when completed, is to have a thickness of at least 2 inches, everywhere equally firm and compact, and jointing closely to the curb of the sidewalks, gutter-covers, etc., and the surface must in every place conform to the prescribed longitudinal transverse profiles.

Laying the Asphalt.—The asphalt is to be laid in dry weather. Work must not be carried on during rains or snowstorms. Only on the special permission of the engineer may the asphalt be laid on the concrete, which is to be thoroughly cleaned of earth, dirt, and loose substances of all kinds. If the cleaning reveals any soft or injured places in the concrete, they are to be chiselled out and filled with new concrete containing a greater proportion of cement. This is not to be covered over until it has set.

All possible measures must be taken to prevent the cooling

of the asphalt powder while being carried to the place where it is to be laid. While the hot powder is being spread out and before the commencement of the tamping and rolling, the greatest care must be exercised in removing all, even the smallest, foreign bodies, such as stones, paper, wood, straw, leaves, cigar-stumps, etc., and no one shall be allowed to throw such bodies on the work. Moreover, the carts in which the asphalt is to be moved must be carefully cleaned after each use. The engineer has the right to require proofs of their cleanliness, and to require a second cleaning under supervision.

303a. American Asphaltum.—There are many localities in the United States where deposits of asphaltum or natural bitumen similar to those of Trinidad, Venezuela, etc., are found. These deposits vary in extent from mere patches to upwards of a hundred acres, and range in depth from a thin crust to several feet.

The origin of these deposits is found in "springs" from which the mineral pitch exudes of about the consistency of thick molasses. The flow from these springs has in the course of time spread over the surrounding surface and become solidified by the evaporation of the lighter oils.

These deposits are generally quite pure, containing from 80 to 92 per cent of bitumen.

These asphaltums are extracted and refined in a manner similar to that described under Trinidad asphaltum, but the paving-cement is fluxed or softened by the addition of natural maltha or semi-liquid asphaltum, instead of by residuum oil.

The paving mixture is prepared of the same materials and in the manner described under Trinidad and Bermudez Asphaltums.

The present useful sources of these asphaltums are Utah and California. The price of the refined asphalt f. o. b. at the mines is about $25.00 per ton.

CHAPTER VI.

BRICK PAVEMENTS.

304. Brick, although one of the oldest materials used for paving, was not employed for this purpose in the United States until about twenty years ago. The first brick pavement laid in the United States was in Charleston, W. Va., in 1872. Since then the use of brick as a paving material has extended over a wide section of country; and in localities with moderate traffic such pavements appear to give satisfaction.

305. The advantages of brick pavements may be stated as follows:

(1) Ease of traction.
(2) Good foothold for horses.
(3) Not disagreeably noisy.
(4) Yields but little dust and mud.
(5) Adapted to all grades.
(6) Easily repaired.
(7) Easily cleaned.
(8) But slightly absorbent.
(9) Pleasing to the eye.
(10) Expeditiously laid.
(11) Durable under moderate traffic.

Brick pavements will be found in many localities to be superior to wood or broken stone, and in many cities and towns will be found superior to stone blocks.

306. The Defects of Brick Pavements.—The principal defects of brick pavements arise from lack of uniformity in the quality of the bricks and the liability of incorporating in the pavement bricks of too soft or porous structure, which crumble under the action of traffic or frost.

The employment of unsuitable brick is liable to be fostered by a popular desire to help a local industry without due regard to the

TYPES OF BRICK PAVEMENTS.

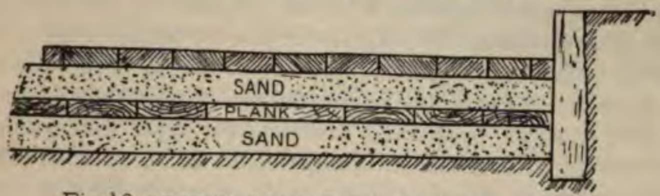


Fig 16 SECTION OF HALE PAVEMENT.

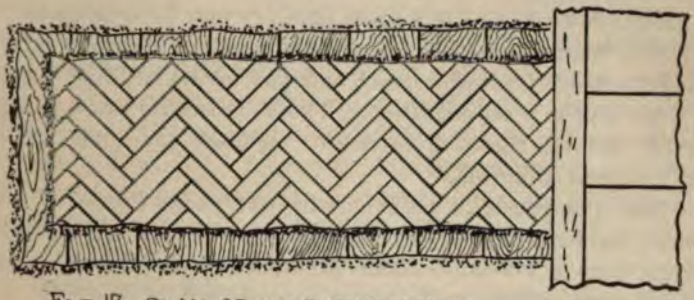


Fig 17 PLAN OF HALE PAVEMENT

Fig 18 SECTION OF BRICK PAVEMENT ON CONCRETE

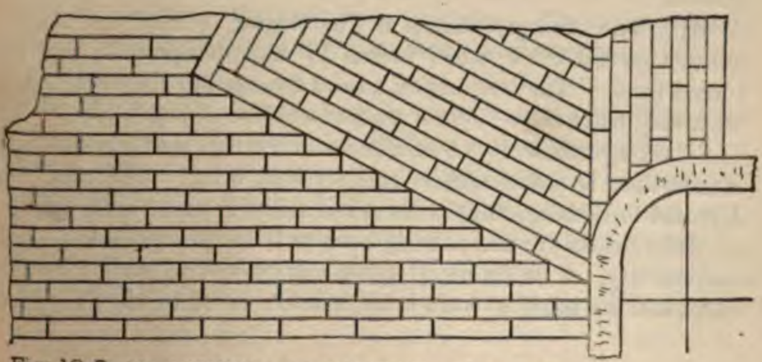


Fig. 19. PLAN SHOWING ARRANGEMENT OF JUNCTION.

quality of the local clays for the manufacture of good paving brick. This circumstance, together with the comparative ease with which contractors who have little experience can bid on this class of work, and the difficulty of rejecting the lowest bid by local authorities, will in many places result in the failure of the brick pavements. If cities, however, in making contracts for brick pavements, will keep these contingencies in mind, and as far as possible exercise discrimination in selecting bricks made especially for this purpose and contractors interested in making these pavements popular, then the development of a great industry may be anticipated.

307. Durability.—Brick has been used for upwards of a hundred years in the Netherlands, and pavements laid half a century ago are still in good condition. There are several brick pavements in the United States from ten to eighteen years old which are still in good condition.

308. The general experience with pavements formed of suitable brick, laid on an unyielding foundation, with the joints filled with bituminous or Portland-cement grout, is that they furnish a smooth and durable surface, well adapted to moderate traffic.

309. Failures of the earlier pavements are frequently reported. These pavements were generally constructed on defective foundations, and with the ordinary building bricks of the locality. Such failures are the result of overhaste in the selection of the material, and poor foundations.

310. The durability of the bricks seems to depend (1) on the clay from which they are made being practically free from lime; (2) on the thorough grinding and mixing of the clay, so as to have no lumps in the bricks; (3) upon the bricks being thoroughly annealed.

311. The brick pavements at The Hague, Holland, are made of a hard-burned brick 8.668 inches by 4.33 inches wide and 2.16 inches thick. They are laid on a sand foundation 7.88 inches deep, with very little clay. Joints are laid as close as possible.

The Hague is a city of residences, and street traffic is very light. Amsterdam is paved almost entirely with brick. The road from Utrecht to Connighem, twenty-seven miles, is paved with brick.

312. Bricks are successfully used in Rotterdam, which is a commercial city. Two classes of brick are used—one made from local clays, and the other a scoria brick, manufactured by the Tees Scoria

Brick Company, of England. The local bricks are preferred for light traffic, and for medium traffic the scoria bricks.

313. Size and Shape of Bricks.—Bricks are passing through an ordeal similar to that through which wood for paving passed many years ago, with practically the same results, viz., that with a proper foundation neither odd shapes, grooves, lugs, nor other devices are necessary or beneficial. Experience shows that the most economical and desirable size for paving bricks is that of the standard building brick. Bricks of this size can be made more cheaply, burned more uniformly, and those which are unsuitable for paving can be utilized for building purposes, which would be impracticable with odd shapes. The imperfect ones of said shapes or peculiar form are so much waste material, and the cost of their manufacture must be added to the price of the good ones in order to protect the manufacturer from loss. Moreover, with irregular sizes and odd shapes it would be necessary for the towns employing brick pavements to keep a large stock of the different bricks on hand to make repairs, which would be expensive and troublesome.

314. Quality of Bricks.—The qualities essential to a good paving brick are the same as for any other paving material, viz., hardness, toughness, and ability to resist the disintegrating effects of water and frost. As with other materials, porous brick are unfit for paving.

These qualities are not obtained, as is commonly supposed, by vitrifying the bricks: in fact the application of the term vitrified to paving bricks is a misnomer. The process of vitrification is to convert into glass by fusion or the action of heat. Glass is a smooth, impermeable, brittle substance, easily fractured; therefore the edges of bricks that are vitrified or turned into glass will be quickly broken off, and their surface will be slippery. Vitrification adds nothing to the strength; in fact it defeats the object for which the bricks are made.

315. The required qualities are imparted to the brick by a process of annealing. The bricks should be burned just to the point of fusion, then the heat gradually reduced until the kiln is cold. This process will produce a brick thoroughly compact, hard, and tough. If the cooling off is done quickly, it will produce a brittle brick, that will speedily go to pieces under traffic.

316. Foundation.—A solid unyielding foundation is as indis-

pensable with bricks as with any other paving material: the failure of the earlier pavements was due, in many cases, more to defective foundations than to defective material. The use of plank laid on sand is objectionable for the same reasons stated under wood pavements, Articles 185, 186.

317. The foundation in all cases should be formed of cement concrete, the aggregate of which, in localities where stone or gravel are unobtainable, may be of broken bricks.

318. Manner of Laying.—The bricks should be laid on edge, as closely and compactly as possible, in straight courses across the street, with the length of the bricks at right angles to the axis of the street. Joints should be broken by at least 3 inches. None but whole bricks should be used except in starting a course or making a closure. Before the closure is made, each single course should be pressed as compactly together as possible with an iron bar applied to the curb end of the row, and then keyed in place with a close-fitting brick. After 25 or 30 feet of the pavement is laid, every part of it should be rammed with a rammer weighing not less than 50 pounds, and the bricks which sink below the general level should be removed and replaced by a brick of greater depth. After the ramming and rectification Portland-cement grout should be poured into the joints until it appears on the surface; then the whole surface should be covered with a layer of dry sand $\frac{1}{2}$ inch deep.

319. At street intersections the course should be laid meeting at an angle, as shown in Fig. 19, so that the courses may not run parallel to the traffic.

320. Cost of Brick Pavements.—The cost of construction of these pavements depends largely upon the facilities for obtaining the requisite material and the character of the foundation.

The cost of a first-class brick pavement per square yard may be estimated as follows:

Excavation	\$......
$\frac{1}{6}$th of a cubic yard of concrete	......
$\frac{1}{12}$th " " " sand	......
72 bricks of standard size	......
Labor laying, etc.	......
Freight	......
$2\frac{1}{2}$ gallons of asphaltic cement	......
Total	\$......

321. Table XXXVII shows the cost in various localities in the United States.

TABLE XXXVII.

EXTENT AND COST OF BRICK PAVEMENTS IN SEVERAL LOCALITIES IN THE UNITED STATES IN 1890.

Cities.	Extent. Miles.	Cost of Construction per square yard.
Columbus, Ohio	21.00	$1.75 to $2.85
Philadelphia, Pa	19.80	2.05
Decatur, Ill	10.00	
Bloomington, Ill	6.00	1.62
Toledo, Ohio	4.70	2.10
Omaha, Neb	3.00	1.75 to 2.14
Parkersburg, W. Va	2.20	1.09 to 1.40
Quincy, Ill	2.00	1.80
Springfield, Ill	1.50	1.50
Bucyrus, Ohio	1.25	2.80
Rochester, New York	1.25	2.25*
Trenton, N. J	1.00	2.00
Nashville, Tenn	0.75	1.85
Detroit, Mich	0.61	2.80
Chicago, Ill	0.38	2.00
St. Paul, Minn	0.34	2.00
Cumberland, Md	0.33	1 25
Wheeling, W. Va	10.00	1.00 to 1.41

* Concrete foundation.

322. Variety of Systems.—Many patented systems of forming brick pavements have been introduced, differing either in the shape and size of the bricks or in the method of laying them. The following are representative systems:

The Hayden Paving-block (Fig. 19*a*).—The shape and manner of laying these blocks is patented. The blocks are square in plan, with deep hollows underneath to facilitate burning and save material; the top surface is flat, broken by indentations, and the edges of the top are bevelled. The blocks are made in two sizes, the smaller ones 5¼ inches deep and 5¾ inches square.

The manner of laying these blocks is as follows: The surface of the street, being brought to the required grade, is covered with 8 inches of broken stone, which is compacted by rolling or ramming; on the broken stone a layer of 2 or 3 inches of sand is spread, on which the blocks are laid. The hollows in the bottom of the

blocks are filled with moist sand, then laid in position, rammed to grade, and the joints filled with hot pitch.

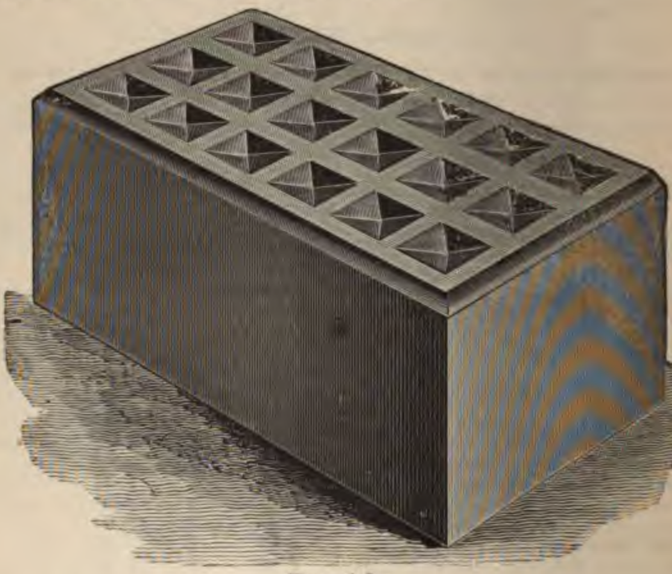


FIG. 19A.

The cost of this pavement is about $1.92 per square yard.

The clay from which these blocks are made is composed of

Silica	76.24	per cent
Alumina	16.87	"
Iron	.16	"
Lime	.50	"
Magnesia	trace	
Alkalies	1.09	"
Water	5.14	"
	100.00	per cent

323. The Halwood Block.—These blocks are composed of a mixture of mica shale, clay, and sand. The blocks measure 3 × 4 × 9 inches, taking 48 to a square yard. They are laid on a foundation of either 6 inches of concrete or 8 inches of broken stone, joints filled with coal-tar. The cost per square yard, including foundation, is from $2.50 to $2.10.

324. The McReynolds Patent Brick.—The patent consists in the bricks having lugs, and in one end of each brick a recess. The claim is that this arrangement permits the joint-filling to flow around the brick, and that these projections act as an obstruction to the cement running during hot weather to the gutter.

325. The Hale Pavement.—Introduced in 1873 is a patent process for laying any brick for paving purposes, the novelty being in the foundation, which consists of 3 inches of sand, on which are laid 1-inch oak boards dipped in coal-tar. The boards are laid either lengthwise or crosswise of the street. On the boards a layer of clean sand from an inch to an inch and a half thick spread, and the bricks laid on edge, "herring-bone" fashion, with the joints filled with tar or sand as may be desired. This costs in West Virginia $1.35 per square yard, varying of course with the cost of the brick used. A royalty of 10 cents per square yard is charged by the Hale Comfor the use of this method (see Figs. 16 and 17).

326. "Charleston Plan."—On the graded surface of the street spread 3 inches of clean coarse sand; on this place 1-inch oak boards dipped in hot coal-tar; on the boards spread a cushion-coat of clean sand 1½ inches deep; on this lay the bricks (common red) on edge, "Herring-bone" fashion; cover the bricks with dry clean sand, and broom well to fill the joints.

327. "Wheeling Plan."—The roadbed is first graded and compacted by rolling with a 5-ton roller, then 3 to 7 inches of coarse gravel and sand is spread and rolled; on this the bricks are laid with their length at right angles to the axis of the street and then brought to a solid bearing by rolling; the joints are filled with sand and coal-tar, and the surface covered with dry sand. Both the common red and special bricks are used.

328. Paving-bricks are made at Kakos near Buda Pesth from carefully selected clay mixed with a little lime. The bricks when moulded are subjected to a pressure of about 3500 pounds per square inch, and then burned nearly to vitrification. The product is regular in form, homogeneous, of uniform density, and of great resistance to wear. According to the experiments of Prof. Ignæz, they have supported without deformation or fissuring a maximum load of over 45,000 pounds per square inch and a mean load of 31,426 pounds per square inch. A square meter (1196 square yards) of this pavement costs $3.80. In forming the paving, the soil is

first consolidated and a bed of ordinary brick masonry is laid upon it; the paving-bricks are set in mortar, leaving a joint of $\frac{4}{10}$ of an inch between them to be filled with cement. The dimensions of the bricks are 7.87 × 7.87 × 3.9 inches and they weigh 24 pounds each. It takes 22 bricks to lay 1 square yard of paving. The brick foundation is 6 inches deep. The pavement made with these bricks is easy to clean, does not become slippery, and is pleasant to drive over. The only objection is that it is somewhat noisy in the narrow streets.

329. Iron Bricks, so called, are said to be used satisfactorily for paving in Germany. These bricks are made by mixing equal parts of finely ground red argillaceous slate and finely ground clay, with the addition of 95 per cent iron-ore. The ingredients thus mixed together are then moistened with a solution of 25 per cent of sulphate of iron to which fine iron-ore is added; after this the compound is shaped in a press, dried, dipped once more in a concentrated solution of finely ground iron-ore, and then baked in an oven for about 48 hours in a reducing-flame.

330. Bricks made from blast-furnace slag and scoria have been tried; they are durable, but soon wear slippery and afford little foothold for horses. Ordinary building-bricks saturated with gas-tar have been experimented with in Nashville, Tenn. The results were not satisfactory, and the pieces of experimental paving have been removed.

331. Heads of Specifications for Brick Pavement.

(1) Preparation of roadbed.

(2) Foundation. (Concrete.)

(3) *Quality of the Bricks.*—The bricks shall be manufactured from suitable clay containing not more than one per centum of lime.

They must be burned especially for paving purposes. They shall have a resistance to crushing of not less than 8000 pounds, per square inch on the flat, and must not absorb more than $\frac{1}{500}$ of their weight of water after 48 hours' immersion. They must possess such a degree of toughness that when struck a quick blow with a 4-lb. hand hammer on the edges, the edges shall not spall or chip.

(4) *Size and Shape.*—They shall be of a uniform size of 8 × 4 × $2\frac{1}{4}$ inches, shall be square on the edges, straight, and free from fire-cracks or checks; when broken, the fracture shall be smooth and

straight, not conchoidal; and the texture shall be uniform throughout and not granular.

(5) *Samples.*—Not less than three bricks of the quality, size, and shape proposed to be used shall be furnished with each proposal, each brick to be labelled with both the bidder's and maker's name and address; these samples shall be deposited in the office of   three days before the time of opening the bids. They will be subjected to the required tests, and the characteristics of those deposited by the successful bidder will become the standard by which will be tested all the bricks to be furnished by him, and no deviation from this standard greater than one per cent in any particular will be permitted in the bricks placed in the work.

(6) *Inspection and Culling.*—The bricks will be inspected after they are brought upon the ground, and all bricks which are soft, cracked, checked, overburned, or otherwise defective in quality or dimensions will be rejected and must be immediately removed from the line of the work. The contractor must furnish such laborers as may be necessary to aid the inspector in the examination and the culling of the bricks; and in case the contractor neglect or refuse to furnish said laborers, such laborers as in the opinion of the   may be necessary will be employed by said   , and the expense thus incurred by   will be deducted and paid out of any money then due or which may thereafter become due to said contractor under the contract to which these specifications refer.

(7) *Cushion-coat.*—On the concrete foundation a layer of clean sharp sand, free from moisture, will be evenly spread to a depth of ½ inch. The sand if not dry must be made so by the application of artificial heat, in such apparatus as may be suitable for the purpose and approved of by the engineer.

(8) *Laying the Bricks.*—The bricks shall be set on the cushion-coat in close contact with each other, both on sides and ends; they will be laid in parallel courses across the street, with the length of the bricks at right angles to the axis of the street. The bricks of adjoining courses shall break joints by at least 3 inches. At street-intersections the bricks will be laid on the diagonal, as shown on the plans. . . . Whole bricks only shall be used, except in starting a course or making a closure and in paving around manhole-heads, etc.

st consolidated and a bed of ordinary brick masonry is laid upon ; the paving-bricks are set in mortar, leaving a joint of $\frac{4}{10}$ of an nch between them to be filled with cement. The dimensions of the bricks are 7.87 × 7.87 × 3.9 inches and they weigh 24 pounds each. It takes 22 bricks to lay 1 square yard of paving. The brick foundation is 6 inches deep. The pavement made with these bricks is easy to clean, does not become slippery, and is pleasant to drive over. The only objection is that it is somewhat noisy in the narrow streets.

329. Iron Bricks, so called, are said to be used satisfactorily for paving in Germany. These bricks are made by mixing equal parts of finely ground red argillaceous slate and finely ground clay, with the addition of 95 per cent iron-ore. The ingredients thus mixed together are then moistened with a solution of 25 per cent of sulphate of iron to which fine iron-ore is added; after this the compound is shaped in a press, dried, dipped once more in a concentrated solution of finely ground iron-ore, and then baked in an oven for about 48 hours in a reducing-flame.

330. Bricks made from blast-furnace slag and scoria have been tried; they are durable, but soon wear slippery and afford little foothold for horses. Ordinary building-bricks saturated with gas-tar have been experimented with in Nashville, Tenn. The results were not satisfactory, and the pieces of experimental paving have been removed.

331. Heads of Specifications for Brick Pavement.

(1) Preparation of roadbed.

(2) Foundation. (Concrete.)

(3) *Quality of the Bricks.*—The bricks shall be manufactured from suitable clay containing not more than one per centum of lime.

They must be burned especially for paving purposes. They shall have a resistance to crushing of not less than 8000 pounds, per square inch on the flat, and must not absorb more than $\frac{1}{500}$ of their weight of water after 48 hours' immersion. They must possess such a degree of toughness that when struck a quick blow with a 4-lb. hand hammer on the edges, the edges shall not spall or chip.

(4) *Size and Shape.*—They shall be of a uniform size of $8 \times 4 \times 2\frac{1}{4}$ inches, shall be square on the edges, straight, and free from fire-cracks or checks; when broken, the fracture shall be smooth and

332. Specifications for Brick Pavements in Memphis, Tenn.—The roadway between curb lines shall be taken down to sub-grade, care being taken not to plough within three inches (3) of the sub-grade stakes, which last shall be carefully removed with pick and shovel, in such manner as to leave a true and perfect surface, which shall be rolled down with a 5-ton roller three times before the concrete foundation is laid. Before the sub-grade foundation is finally fixed, all water and gas pipes must be put in and adjusted; water-pipes must be of lead, double strength, and the gas of the best galvanized pipe; the trenches shall be filled in layers of three inches, and carefully rammed to within six inches of sub-grade and the balance of trench concreted.

Concrete.—Upon the sub-grade thus formed shall be spread the concrete foundation, composed of hard limestone, broken or crushed to pass a two-inch ring,—the same to be free of all dirt, trash, etc.,—clean, sharp sand mixed with fine gravel, and the best fresh Louisville cement, in the following proportions, viz., one measure of cement and two of sand, thoroughly mixed, and then made into mortar, with the least possible amount of water; into this will be put the macadam, which shall first be well wet, and the whole worked into a concrete in such quantities as will produce a surplus of free mortar when well rammed. This proportion, when ascertained, will be regulated by measure. Each total of concrete will be thoroughly mixed, in suitable boxes, with hoes and shovels, the mortar always to be mixed fresh before being applied to the broken stone. It will then be spread and at once thoroughly compacted by ramming with heavy cast-iron rammers, until free mortar appears on the surface: the whole operation shall be done as expeditiously as possible. The upper surface will be made exactly parallel with the surface of the pavement to be laid, by floating over the surface with cement and the straight edge. The depth of concrete consolidated shall not be less than nine (9) inches. No walking or driving shall be permitted on the concrete when it is setting, and it shall be allowed to set for three (3) days before any pavement is laid on it.

Pavement.—On the concrete foundation thus prepared a bed of clean, sharp sand, free from moisture, two (2) inches deep, shall be laid. The paving bricks to be used shall be such as shall be satisfactory and acceptable to the Engineer, and shall conform

strictly to the samples offered by the contractor, and accepted by the Engineer and the Council. The sand must be brought to a true and perfect surface, and made to conform strictly to the grade pegs set by the Engineer, by means of a drag straight-edge, seven (7) feet long. drawn over the surface, and resting on two pieces of scantling $2\times4\times16$ feet long, having planed surfaces, the top of the sand bed being flush with the grade pegs. Upon this bed of sand the paving bricks are to be laid on edge, at right angles to the line of curbs, in parallel lines, in as close contact as possible on sides and ends; the joints broken one with another, by starting at curb-lines with half-bricks, in alternate rows, so as to break the joints. No half or broken brick shall be laid except at the curb-lines, in order to make closures, but the brick must be laid whole throughout, except as above named.

As the pavement is laid over thirty or more feet at a time, it shall be thoroughly rammed over three times with a flat iron rammer, about one foot in diameter, weighing thirty or forty pounds, which must be done by lifting and dropping the rammer vertically. When the bricks have been rammed to a solid bearing and brought to a perfect surface, the interstices shall then be thoroughly and completely filled, from bottom to top, with distilled coal-tar pitch (known as No. 6) heated up to 300 degrees. All crevices must be filled, and the entire top surface covered to a depth of not less than one fourth inch, and upon this must be spread one fourth inch of clean, sharp sand, which must be comparatively dry and free from moisture. This sand must be thrown evenly over the boiling pitch as rapidly as the pavement is filled in, and the pitch spread over the surface of pavement, the aim and object being to make the pavement one solid mass, which, when completed, shall be practically a fixture and water-tight. The bricks shall be rigidly inspected before being laid in the pavement, and all objectionable ones removed. The sand and pitch shall be acceptable, and shall also be applied as directed by the Engineer, or his assistant, and to his entire satisfaction and acceptance. The pavement, when completed, must be smooth, and conform to the grades given by the Engineer.

Dimensions of Brick.—Square-edged, to wit: Length, $8\frac{3}{4}$ inches; thickness, $2\frac{3}{4}$ inches; width, 4 inches. Halwood block, patent length, 9 inches; width, 4 inches; thickness, 3 inches.

Bricks thoroughly burned throughout to vitrification.

333. Extracts from Specifications for Laying Brick Pavements in the City of Bloomington, Ill.

Roadbed.—The roadbed shall be carefully graded and shaped to an elevation of at least eleven inches below the established grade line given by the City Engineer, and intended for the surface of the pavement when completed. The City Engineer, or his assistant, shall set all grade stakes, and thereafter the same must be protected and maintained by the contractor and his employees until the services of the same are no longer needed. The contractor shall do all necessary grading and shall provide all earth necessary for filling, and dispose of all surplus excavation by removing the same to the lawns or other dirt streets as the City Engineer may direct. In order to bring the roadbed to the proper shape and grade, a pattern made under the direction of the City Engineer, giving the street proper convexity, shall be continuously used as a guide to the graders. After said roadbed is properly graded and shaped it shall be thoroughly rolled and compacted by the steam roller, wherever it is practicable to use said roller; and wherever the use of the steam roller is impracticable the foundation shall be compacted either by the use of the smaller roller or by tamping. The roadbed, being properly rolled, shall then be covered with cinders of a uniform depth of at least three inches, and the same shall be rolled and compacted as before; and there shall then be spread a covering of sand of sufficient thickness to grade the surface of said roadbed to a uniform shape, regular and smooth surface for receiving the bottom course of brick. Should any depressions appear during the process of rolling, such as the settlement of sewer branches or otherwise, the same must at once be filled up and again rolled, so that, when the process of rolling shall cease, the entire roadbed shall be uniform and complete in its settlement.

Brick Work.—There shall then be placed a course of brick upon their flat surface, long dimensions parallel with the street, laid as closely together as practicable and all joints broken. Dry sand, screened, will then be spread over the entire course of brick, and well brushed in so as to completely fill all crevices. Sufficient screened sand will then be placed on the bottom course of brick to make a bed of one inch depth upon which to place the top course of brick. The top course of brick will then be laid on their longest

two-inch surface across the street, breaking joints and laying the brick as closely together as possible. Nothing less than whole bricks to be used in the top course except were necessary to break joints. The courses of brick in the top course must be kept straight across the street, at right angles to the curbing as near as practicable. Brick that are badly swelled and irregular will not be permitted in the top course. They must constitute a good quality of "paving-brick," maintaining uniformity and regularity in shape to such a degree as will be consistent with a first-class pavement, and render satisfaction to the Engineer in charge. The bottom course of brick must be composed of a good quality of such as are known as "sidewalk brick." The top course of brick, having been laid as above provided, must then be covered with screened sand and rolled with a roller weighing at least two tons. During this final process of rolling the sand must continually be brushed into the pavement so as to effectually fill all crevices. All such work shall be under the supervision and subject to the approval of the Engineer.

334. Specifications for brick pavements differ widely in their requirements. As yet no standard method of construction or of testing the quality of the brick has been arrived at.

A variety of methods of construction are in vogue, and each one has its advocates and opponents. Thus we find in one place a foundation of sand, in another sand and boards, in another gravel, in others broken stone laid in the form of a Telford foundation, in others broken-stone concrete, and so on.

As to the quality of the brick no definite requirements have been determined. In the absence of determined qualities it has of course been impossible to adopt a uniform system of tests, and the majority of tests published are of little value from this want of uniformity.

The specifications relating to the quality of the brick to be used are generally vague; the majority recite that "the brick used shall be hard, free from defects of any kind, manufactured and burned especially for street-paving purposes, be equal in all respects to the sample filed with the proposal, and subject to inspection and acceptance or rejection by the engineer or inspector." This statement of the qualities required defines in reality but very little. The term *hard* is an indefinite one; a hard brick in one locality may be known as a soft one in another. Without a definite state-

ment as to what constitutes defects there may be differences of opinion as to whether or not they exist in a given article, as well as to the *equality* of goods furnished with the sample deposited.

The characteristic qualities and strength of the material are not clearly defined, or in such manner as will enable the bidder to correctly interpret the meaning. The power to accept or reject, although nominally in the hands of the engineer, is indefinite and unsupportable, because the acceptance or rejection cannot be made in accordance with known provisions and fixed rules. In the absence of recognized standards two courses are open in order to secure the desired qualities, avoid indefiniteness and controversy; namely, (1) to reserve the right to make, before awarding the contract, any test that the engineer may see fit to make, and award the contract in accordance with the results of such tests; or (2) prescribe in the specifications the definite tests to which the material will be subjected, with such reservations as to time and place as the exigencies of each particular place seem to demand.

CHAPTER VII.

BROKEN-STONE PAVEMENTS.

335. As near as can be ascertained, the first broken-stone pavements were constructed in France in 1764 by one M. Tresaguet, who built many miles of such pavements in the latter part of the last century. In the early part of the present century two systems were introduced into England, the first by Telford, the second by Macadam.

336. The name of Telford is associated with a rough stone foundation, which he did not always use, but which closely resembled that which had been previously used in France. Macadam disregarded this foundation, contending that the subsoil, however bad, would carry any weight if made dry by drainage and kept dry by an impervious covering. The names of both have ever since been associated with the class of road which each favored, as well as with roads on which all their precepts have been disregarded.

337. The following specifications show the difference in the methods of the inventors.

338. Tresaguet's Method, 1764 (Fig. 21).—"The bottom of the foundation is to be parallel to the surface of the road. The first bed or foundation is to be placed on edge and not on the flat, in the form of a rough pavement, and consolidated by beating with a large hammer; but it is unnecessary that the stones should be even one with the other. The second bed is to be equally placed by hand, layer by layer, and beaten and broken coarsely with a large hammer, so that the stones may wedge together and no empty spaces remain. The last bed, three inches in thickness, is to be broken to about the size of a nut with a small hammer, on a sort of anvil, and thrown upon the road without a shovel to form the curved surface. Great attention must be given to choose the hardest stone for the last bed, even if one is obliged to go to more

distant quarries than those which furnish the stone for the body of the road. The solidity of the road depending on this latter bed, one cannot be too scrupulous as to the quality of the materials which are to be used for it."

Fig. 20. FRENCH. PREVIOUS TO 1775.

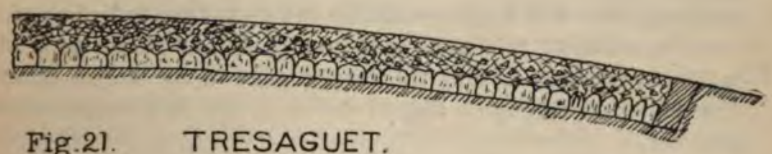


Fig. 21. TRESAGUET.

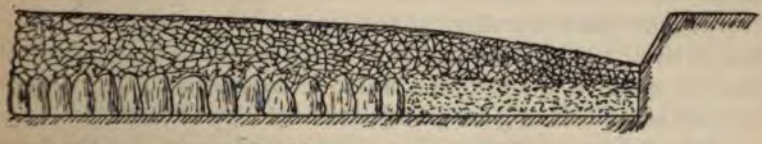


Fig. 22. TELFORD.

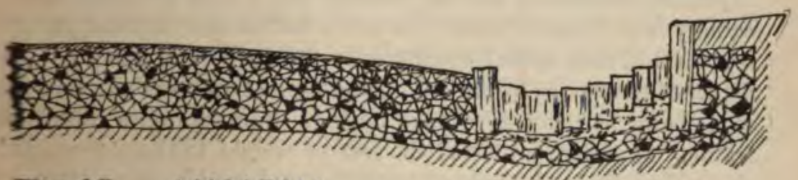


Fig. 23. MACADAM.

339. Telford's Method, 1824 (Fig. 22).—"Upon the level bed prepared for the road materials a bottom course or layer of stones is to be set by hand in the form of a close firm pavement. The stones set in the middle of the road are to be seven inches in depth; at nine feet from the centre, five inches; at twelve feet

from the centre, four inches; and at fifteen feet from the centre, three inches. They are to be set on their broadest edges lengthwise across the road, and the breadth of the upper edge is not to exceed four inches in any case. All the irregularities of the upper part of the said pavement are to be broken off by the hammer, and all the interstices to be filled with stone chips firmly wedged or packed by hand with a light hammer, so that when the whole pavement is finished there shall be a convexity of four inches in the breadth of fifteen feet from the centre.

"The middle eighteen feet of pavement is to be coated with hard stones to the depth of six inches. Four of these six inches to be first put on and worked in by carriages and horses; care being taken to rake in the ruts until the surface becomes firm and consolidated, after which the remaining two inches are to be put on.

"The whole of this stone is to be broken into pieces, as nearly cubical as possible, so that the largest piece in its largest dimensions may pass through a ring of two and one half inches inside diameter.

"The paved spaces on each side of the middle eighteen feet are to be coated with broken stones or well-cleaned gravel up to the footpath or other boundary of the road, so as to make the whole convexity of the road six inches from the centre to the sides of it, and the whole of the materials are to be covered with a binding of an inch and a half of good gravel free from clay or earth."

340. Macadam's Method (Fig. 23).—Macadam omitted the foundation of large stones, claiming that it was not only useless but injurious; he placed on the natural soil a layer of stone broken equally into cubes of about one and a half inches in their greatest dimensions, and spread equally over the surface of the road to a depth of ten or twelve inches. Binding material was not used, the stone being left to work in and unite by its own angles under the traffic. Macadam preferred the test of weight to that of measurement, and insisted that no stone should weigh more than six ounces, which is the weight of a cube of one and a half inches of hard compact limestone; his overseers were provided with small scales and a six-ounce weight to test the larger stones.

Although Macadam was the pioneer of good road construction in England, and from whose name the word *macadamized* is derived, it may be observed that he had been anticipated in the pro-

mulgation of the system of a regularly-broken stone covering by Mr. Edgeworth, an Irish proprietor, whose treatise on roads, of which the second edition was published in 1817, contains the results of his experiments on the construction of roads, with some useful rules. He advocated the breaking of the stones to a small size, and their equal distribution over the surface. He also recommended that the interstices should be filled with small gravel or sharp sand—a practice which, though condemned by Macadam, is now adopted by the best roadmakers.

341. Since Telford and Macadam's time the practice of road-making has been greatly improved by the introduction of rollers and stone-crushing machinery.

342. Modern Telford.—On the natural-soil bed, properly graded, a layer of stones eight inches thick is set by hand, arranged and wedged as described by Telford. On the stone foundation so prepared a layer of broken stone of a size not exceeding three inches is evenly spread and rolled; the surface so rolled is covered with a layer of sand one-half inch thick, and the rolling continued; then a layer of stones not larger in any dimension than two inches is spread to a depth of four inches and rolled, followed as before with a layer of sand and also rolled. Finally a coating of clean sharp sand is applied, well watered, and the rolling continued until the surface becomes smooth. The surplus sand is then swept off and removed.

343. Modern Macadam pavements are constructed in the manner above described, only omitting the stone foundation, and the depth of the stone varies from four to twelve inches.

344. Defects of the Telford System.—(1) No matter how carefully the interstices between the foundation-stones are filled with chips, a large percentage of voids is left giving free access to water, thus defeating the object of the covering, which is to preserve the natural soil from contact with water. The pavement acts as a drain; the natural soil becomes saturated with water, and a slow but constant sinking of the bottom stone into the subsoil and a slow but gradual rising of the natural soil takes place, the cohesion of the superstructure is destroyed, and it finally becomes a mass of mud and stones.

(2) If the foundation be of a harder rock than the covering, it becomes an anvil on which the softer stones are pounded to pieces by the passing loads.

(3) The stone foundation unnecessarily increases the cost of construction. The roads of Central Park, N. Y., are excellent examples of the Telford system. They are of indefinite thickness, reposing on a bed of thoroughly drained earth; they were constructed and are maintained at a cost that is prohibitory to an extensive use of such pavements.

345. Defects of the Macadam System.—The broken stone laid as directed by Macadam cannot be impervious, because the interstices compose one half of the bulk of loosely spread stones, and no amount of rolling will reduce the voids more than one fourth; and as nature abhors a vacuum, the subsoil when moistened will rise up and fill the vacant space, and the weight of the traffic will force the lower stones down until the whole becomes a mass of mud and stones, as shown by the following analysis of a portion of the crust of the macadamized roads in the Mall, St. James Park, London:

ANALYSIS OF MACADAMIZED ROAD CRUST.

Mud	11.00	cu. ft.	or	41.00	per cent
Sand with pebbles not exceeding $\frac{3}{16}$ of an inch	2.40	"	"	9	"
Stones from $\frac{3}{16}$ to $\frac{1}{2}$ inch	6.56	"	"	24	"
" " $\frac{1}{2}$ to 1 inch	4.48	"	"	$16\frac{1}{2}$	"
" " 1 to $2\frac{1}{4}$ inches	2.56	"	"	$9\frac{1}{2}$	"
Total volume	27.00	cu. ft.	or	100.00	per cent

From this analysis it appears that less than $9\frac{1}{2}$ per cent, say one tenth of the original stone, escaped underground, whilst 40 per cent of it was reduced to the state of mud.

346. Advantages of Broken-stone Pavements.

(1) Good foothold.

(2) Reasonably easy traction when in good condition.

(3) Moderate first cost.

(4) Comparatively noiseless.

347. Defects Common to all Broken-stone Pavements.

(1) Mud when wet.

(2) Dust when dry.

(3) Excessive cost of maintenance under heavy traffic.

(4) Impossibility of keeping them clean.

348. The foregoing defects condemn the use of broken stone for city streets, yet when properly built and maintained broken

stone forms the pleasantest, safest, and most economical road-surface known for city suburbs and country highways.

Ideally perfect broken-stone road construction has never been attained, and never will be until our road constructors abandon obsolete precedents and construct road-coverings that will be adapted to the requirements of the traffic and impervious to water and frost.

349. Essentials Requisite to Successful Construction.—The essentials requisite to the successful construction of broken-stone pavements may be summed up as follows:

(1) The entire removal from the roadbed of all vegetable or perishable matter.

(2) The removal of the natural soil to such depth as may be determined by its character, and by the thickness of the intended covering.

(3) Sub-surface drainage wherever required.

(4) The thorough compacting of the natural-soil bed.

(5) The employment of sand or gravel for the foundation.

(6) The employment of the best materials afforded by the locality.

(7) The employment of unscreened stones.

(8) The complete exclusion of clay or loam from the broken stone.

(9) The employment of sand or gravel for binding, in sufficient quantity to fill the voids.

(10) The thorough compacting of the broken stone with a roller of competent weight and suitable form.

350. Erroneous Methods of Construction.—Broken-stone pavements can be made very unsatisfactory and defective by:

(1) A permeable foundation.

(2) By the use of excessively hard stones which no amount of rolling will consolidate.

(3) By the use of improper binding material, such as loam and clay.

(4) By an undue proportion of soft among hard stones. A small quantity (about one fourth) of soft stones judiciously mixed with the harder will be an undoubted advantage.

(5) By employing stones of too large a size.

(6) By screening the broken stone, thus removing the chips and

dust which otherwise would assist in filling the voids. Screening should not be practised, except when an injurious amount of clay or loam has become mixed with the stone.

(7) By assorting the stone and laying it in layers according to the size of the stone. The practice of forming a road with strata of screened stone assorted in different sizes and growing smaller and smaller towards the top is erroneous; the smaller stone will find its way to the bottom, and the larger stone will work to the surface and ruts will be quickly formed. It will be porous, and no matter how heavily rolled it will be continually crumbling.

(8) By covering the surface of the compacted stone with a layer of stone-dust.

(9) By the use of an excessive quantity of binding material.

(10) By the use of an excessive quantity of water when rolling.

351. Quality of the Stones.—The materials used for broken-stone pavements must of necessity vary very much according to the locality. Owing to the cost of haulage, local stone must generally be used especially if the traffic be only moderate. If, however, the traffic is heavy, it will sometimes be found better and more economical to obtain a superior material, even at a higher cost, than the local stone; and in cases where the traffic is very great, the best material that can be obtained is the most economical.

352. The qualities required in a good road stone are hardness and toughness and ability to resist the disintegrating action of the weather. These qualities are seldom found together in the same stone. Igneous and silicious rocks, although frequently hard and tough, do not consolidate so well nor so quickly as limestone, owing to the sandy detritus formed by the two first having no cohesion, whilst the limestone has a detritus which acts like mortar in binding the stones together.

353. A stone of good binding nature will frequently wear much better than one without although it is not so hard. A limestone road well made and of good cross-section will be more impervious to wet than any other, owing to this cause, and will not disintegrate so soon in dry weather, owing partly to this and partly to the well-known quality which all limestone has of absorbing moisture from the atmosphere. Mere hardness without toughness is not of much use, as a stone may be very hard but so brittle as to be crushed to

powder under a heavy load, when a stone not so hard but having a greater degree of toughness will be uninjured.

354. The most efficient and economical rocks are basalt and syenite. Granite is unsuitable; the mica causes it to break up and grind away quickly. Gneiss is worse than granite. The slate rocks and mica schists are unsuitable. Clay slates are useless, as they crumble on exposure or degenerate into mud. The quartzose grits and silicious grits mixed with limestone form excellent roads. The carboniferous and transition limestones are fairly durable and make smooth and pleasant roads for light traffic and pleasure-drives. Field stone and river stone has been much used in some districts of England; they generally make a rough road, as they are composed of the hardest parts of those stones which have resisted the action of the weather, and are, though frequently very hard, of unequal hardness, so that they wear very irregularly.

355. Coefficients of quality for various road materials have been obtained by the engineers of the French "Administration des Ponts et Chaussées." The quality was assumed to be in inverse proportion to the quantity consumed on a length of road with the same traffic, and measurements were systematically made of the traffic and wear to arrive at correct results, these processes requiring great care and considerable time. Direct experiments on resistance to crushing and to abrasion and collision were made on 673 samples of road materials of all kinds. The coefficients obtained by these experiments were found to agree fairly well with those arrived at by actual observation of the wear in the roads, and are summarized in Table XXXVIII. The coefficient 20 is equivalent to "excellent," 10 to "sufficiently good," and 5 to "bad."

356. The experiments were conducted as follows: The apparatus employed to determine the resistance to wear consisted of cylindrical boxes of iron about 8 inches in diameter and 13 inches long, mounted on an axle revolving horizontally, and so cranked as to hold the axes of the boxes at an angle of 30 degrees with the axis of revolution. In each box was placed 5 kilograms of the broken materials to be tested, carefully cleansed from dust by washing, and the boxes put in motion at a rate of 2000 revolutions per hour. The stones rolled against one another, and were thrown from one end of the box to the other at each revolution. After 5 hours or 10,000 revolutions the boxes were opened, the detritus resulting

from the rubbing and collision was carefully collected and sorted, and the weight of all of less diameter than $\frac{1}{16}$ inch, compared with that of the original samples, gave the degree of wear. It was found that the best materials seldom gave less than 20 grams of detritus per kilogram, and the coefficient of 20 was, therefore, adopted for materials having that proportion of wear. For other materials the coefficient was derived from the proportion

Grams of detritus :: 20 : 20 :: coefficient.

Resistance to crushing was determined by means of an hydraulic press. Experience having shown that cubes of the hardest materials rarely resisted more than 3000 kilograms per square centimeter (equal to about 19 tons per square inch) the coefficient of 20 was given to materials presenting that degree of resistance, and other coefficients were derived from the proportion

3000 : crushing weight per square centimeter :: 20 : coefficient.

In the experiments every precaution to insure accurate results was taken. When the materials were already rounded, as pebbles, they did not wear much in the machine, and obtained a coefficient far above their value; and there were anomalies with a few other materials, such as chalk flints with a softer coating, and stones with cavities. The size to which the stones were broken did not seem to have much influence on the wear.

TABLE XXXVIII.

COEFFICIENTS OF QUALITY.

Materials.	Coefficient of Wear.	Coefficient of Crushing.
Basalt	12.5 to 24.2	12.1 to 16
Porphyry	14.1 " 22.9	8.3 " 16.3
Gneiss	10.3 " 19.0	13.4 " 14.8
Granite	7.3 " 18.0	7.7 " 15.8
Syenite	11.6 " 12.7	12.4 " 13.0
Slag	14.5 " 15.3	7.2 " 11.1
Quartzite	13.8 " 30.0	12.3 " 21.6
Quartzose sandstone	14.3 " 26.2	9.9 " 16.6
Quartz	12.9 " 17.8	12.3 " 13.2
Silex	9.8 " 21.3	14.2 " 17.6
Chalk flints	3.5 " 16.8	17.8 " 25.5
Limestone	6.6 " 15.7	6.5 " 18.5

357. Size of Stones.—The stones should be broken into fragments as nearly cubical as possible. The size of the cubes will depend upon the character of the rock. If it be granite or trap, they should not exceed 1½ inches in their greatest dimensions; if limestone, they should not exceed 2 inches.

358. The smaller the stones the less the percentage of voids. Small stones compact sooner, require less binding, and make a smoother surface than large ones.

359. It is not necessary nor is it advisable that the stones should be all of the same size; they may be of all sizes under the maximum. In this condition the smaller stones fill the voids between the larger and less binding is required.

FIG. 24.—SIZE AND SHAPE OF STONE FOR BROKEN-STONE PAVEMENTS.

The proper shape of broken stone is shown in Fig. 24.

360. Breaking the Stone.—Breaking stone for the purpose of using it as a road-covering was until quite recently always effected by hand; now by the use of machinery it is more quickly and cheaply broken.

361. Hand-broken stone still finds favor with European engineers; they claim that it is better broken and has sharper angles than that broken by crushing: and in many districts the occupation affords employment for persons who otherwise would be thrown upon the public for support.

362. In breaking stone by hand the breaker sits and strikes the stone with a small cast-steel chisel-faced hammer, weighing about

one pound, fixed at the end of a long, straight-grained but flexible ash stick. The breaker also has another hammer, weighing about five pounds, with which he reduces the size of the large stones before breaking them into proper size. Each breaker is furnished with a gauge-ring through which the stones must pass in every direction.

363. The great cost of hand-broken stone led to the employment of machine crushers; their use effected a reduction in the cost of from 50 to 200 per cent, and increased the amount of daily output from 1 to 50.

364. The objections to machine-broken stone are principally:

(1) Want of uniformity in the size of stones.

(2) The stone is frequently flaky with rounded edges, which is a very disadvantageous form for compacting.

(3) Very tough stones have frequently to be passed several times through the machine before they get properly broken.

(4) Very soft stones are crushed to powder.

365. Cost of Breaking Stone.—The cost of breaking stone by hand will vary considerably in different localities on account of the character of the stones to be broken and the value of labor.

366. The average amount of stone broken by a good stone-breaker is given by Mr. Codrington in his work on the Maintenance of Macadamized Roads as follows: Hard silicious stones and igneous rocks, 1 to $1\frac{1}{2}$ cubic yards per day; granite, $\frac{1}{2}$ cubic yard per day; river gravel, field-stones, or flints, 3 to 4 cubic yards per day.

367. The cost of a stone-crushing plant and expense of operating may be taken as follows:

Cost of crusher, engine, and boiler set up, complete		$2500.00
Cost of operating:		
1 engineman and fireman	$3.00	
2 laborers feeding	3.50	
2 tons of coal	8.00	
Oil, waste, etc.	2.00	
Repairs	10.00	$26.50

The product will vary with the toughness of the stone to be broken and the size of the machine.

368. The wear and tear of a stone-crusher is very considerable; it has been known to reach as high as 62.5 per cent of the first cost of the machine in one year.

369. To make a stone-breaking machine pay, it is necessary—

(1) To give it nearly constant work.

(2) To exercise care in feeding, to give a sufficient supply without allowing an undue quantity of stone to pass in at one time.

(3) That the machine shall be so located as to reduce to the minimum the expense of handling both the unbroken and the broken stone.

The dimensions and capacity of several crushers are given in Chap. XXIII.

370. It is impossible to estimate the cost of getting the unbroken stone to the crusher and the broken stone back to the road, for that depends entirely upon the distance which must be traversed in cartage and the condition of the grounds over which the loads are hauled. If the loads have to be hauled a considerable distance to or from the crusher, or if heavy grades have to be ascended or rough ground traversed, the time occupied in hauling each load will be increased and less can be hauled in a day, thus lessening the work done by horses and drivers for each day's wages.

Where stone is to be obtained in more than one place along the line of the projected road, it is sometimes more economical to take the crusher to the stone than to have to haul the broken stone a great distance. For this purpose the crusher can be mounted on wheels and the steam roller used to haul and drive the crusher, without the expense of a fixed plant for crushing stone.

371. Cost of Quarrying and Crushing Stone.—The report of the Board of Street Commissioners of the city of Hartford, Conn., for the year 1890 contains the following table of the cost of quarrying and crushing stone for the past ten years.

The increase in the cost of quarrying and crushing stone during the past year is in part chargeable to the extra cost of hauling the stone to the crushers, on account of the added distance at which the stone was procured, also in part by the expense connected with the opening of new quarries.

372. Voids in the Broken Stone.—The voids of broken stone in which the size and shape of the pieces are nearly uniform are about one half the mass. If the pieces are not uniform, the voids are about four tenths of the mass. The voids in gravel vary, but average about one half of the mass. The greatest amount of rolling will not reduce the voids more than one half of the primitive bulk.

TABLE XXXIX.

COST OF QUARRYING AND CRUSHING STONE.

Year.	Cost of Quarrying per cubic yard.	Cost of Crushing per cubic yard.	Cost of Carting to Breaker per cubic yard.	Total Cost of Crushed Stone at the Quarry per cubic yard.	Average Cost Delivered on the Streets per cubic yard.
1881........	.655 ct.	.536 ct.	.283 ct.	$1.47	$1.70
1882........	.781 ct.	.348 ct.	.237 ct.	1.36	1.87
1883........	.638 ct.	.265 ct.	.247 ct.	1.15	1.59
1884........	.665 ct.	.372 ct.	.228 ct.	1.26	1 70
1885........	.658 ct.	.342 ct.	.224 ct.	1.23	1.66
1886........	.590 ct.	.289 ct.	.233 ct.	1.12	1.65
1887........	.595 ct.	.345 ct.	.281 ct.	1.22	1.64
1888........	.658 ct.	.221 ct.	.288 ct.	1.17	1.63
1889........	.694 ct.	.319 ct.	.263 ct.	1.28	1.69
1890........	.889 ct.	.407 ct.	.301 ct.	1.597	2.045

A well-rolled road-covering contains from 70 to 80 per cent of stone.

373. Determination of the Voids in Broken Stone.—The proportion of voids may be determined by experiment in either of the following ways: (1) Determine the specific gravity of the material, and from that the weight of a unit of volume of the solid. Weigh a unit of volume of the loose material. The difference between the weights divided by the first gives the proportion of the voids. (2) Wet the loose material thoroughly, fill a vessel of known capacity with it, and then pour in all the water the vessel will contain. Measure the volume of water required and divide this by the volume of the vessel; the quotient represents the proportion of voids.

The smaller the stone is broken the less the percentage of voids and the heavier a cubic yard will weigh.

374. Weight of Broken Stone.—To ascertain the weight of a cubic yard of broken stone, multiply the weight of a cubic yard of the given stone by the proportion of voids (usually 0.50); the result will be the weight of a cubic yard of the stone when broken.

375. Area covered by One Cubic Yard of Broken Stone.—A cubic yard of ordinary broken stone will, when properly spread, cover an area of about 32 square yards of surface of a roadway.

Since a cubic yard of loose broken stone contains only one half

of its volume, or $13\frac{1}{2}$ cubic feet of solid stone, its weight, allowing 12 cubic feet of solid granite to one ton, is approximately

$$1 \times \frac{13.5}{12.0} = 1\frac{1}{8} \text{ ton.}$$

Again, one cubic yard is equivalent to 36 square yards 1 inch deep; and 1 ton of stone laid without compression to a depth of 1 inch covers an area of $36 \times \frac{1}{1\frac{1}{8}} = 32$ square yards. When the stone is laid and rolled the primitive volume is reduced by about one fourth; and 1 ton of rolled stone laid to a depth of one inch covers an area one fourth less than 32, or $32 \times \frac{3}{4} = 24$ square yards.

376. To Find the Area that can be covered by One Ton of Stone, when the Thickness of the Layer is given.—Divide 32 by the thickness of the layer in inches if unrolled; or divide 24 by the thickness of the layer in inches when rolled. The quotient is the area in square yards.

377. To Find the Area that can be covered by One Cubic Yard of Broken Stone, when the Thickness of the Layer is given.—When the stone is not rolled, divide 36 by the thickness in inches; the quotient is the number of square yards that can be covered. When the stone is rolled, divide 27 by the final thickness in inches; the quotient is the number of square yards.

378. Thickness of the Broken Stone.—The offices of the stone are to endure friction and shed water; its thickness must therefore be regulated by the quality of the material and the amount of the traffic, and not by any consideration as to its own independent power of bearing weight. Macadam considered 10 inches as sufficient for any traffic on any substratum: experience has proved this true in the well-drained and well-kept roads of Europe.

379. The proper rule is to vary the thickness according to the traffic and the grade. Roads of sharp descent do not require as thick covering as those having flat grades.

Mr. J. Owen, County Engineer of Essex County, N. J., adopted the following thicknesses with good results:

For grades flatter than 1%	10 inches
" " between 1% and 4%	8 "
" " over 4%	6 "

The roads of Bridgeport, Conn. (upwards of 50 miles), built under the direction of Mr. B. D. Pierce, are, with the exception of two short pieces, only 4 inches thick. These roads are subjected to a regular traffic of loads averaging 6000 pounds each; they give entire satisfaction to the public using them, and an ordinary team hauls a net load of 3000 pounds over them.

380. Many roads of 4 and 6 inches thickness have been built that have not proved satisfactory. Their failure is generally attributed to their thinness. This is erroneous; the fault does not always lie in the thinness of the stone covering, but in the method of construction followed. The thin roads that fail are as a rule made by throwing the broken stone on an undrained and unrolled earth roadway, frequently without even removing the mud which covers its surface. In some few cases the stones are rolled with a horse roller, but in the majority the stone is left to be consolidated by the traffic. If roads are to be built in this manner, they must be massive; but no matter how massive they be made, they will have no cohesive strength, they will never be impervious to the mud from below or the rain from above, and will always be unsatisfactory.

381. Sand Core for Broken-stone Pavement.—On a well-drained foundation a sand or gravel core will be found as mechanically serviceable as the most costly stone foundation. Such a core covered with a layer of stone measuring when compacted 4 inches thick will form a finer and more lasting surface than a greater thickness of stone laid upon the earth soil and compacted. Telford was aware of this fact; he was willing to prevent by almost any means available the coming in contact of his road material with the earth subsoil, and suggested gravel, sand, or chalk as alternatives to bottoming stones. A requisite, whatever the medium, was that "this bottoming should be made perfectly firm and regular, so as to receive the top workable metal of equal thickness." Thus, although he always advised a paved bottom when it could be had, many miles of roadway were made under Telford's direction without the paved bottom with which his name is associated.

382. The quantity of broken stone required per mile of road for different widths and thicknesses is given in Table XL.

383. Spreading the Stone.—The stone should be hauled upon the roadbed in broad-tired two-wheeled carts and dumped in heaps,

TABLE LX.

NUMBER OF CUBIC YARDS OF BROKEN STONE REQUIRED PER MILE OF ROAD.

Depth of Stone in Inches.	Width of Pavement in Feet.							
	8	16	24	30	32	40	48	60
4	645	1,290	1,935	2,421	2,580	3,225	3,870	4,842
6	968	1,935	2,903	3,632	3,872	4 840	5,808	7,264
8	1,290	2,580	3,870	4,842	5,160	6,450	7,740	9,684
10	1,613	3,225	4,838	6,053	6,452	8.065	9,678	12,106
12	1,935	3,870	5,805	7,263	7,740	9.675	11,610	14,526
14	2,258	4,515	6,773	8,474	9,032	11,290	13,548	16,948
16	2,580	5,160	7,740	9,684	10,320	12,900	15,480	19,368

and be spread evenly with a rake in a layer of as nearly uniform thickness as may be.

384. Thickness of the Layers.—The thickness of the layers will depend upon the final thickness of the covering. If the finished thickness is to be 6 inches, each layer should be of a depth of $4\frac{1}{2}$ inches.

385. Macadam insisted that the stone should not be laid in shovelfuls but scattered over the surface, one shovelful following another and spreading over considerable space. His object in this was to avoid an accumulation of soft stones at one spot, for the rocks from which the stone was obtained were not of uniform hardness, but of all qualities gathered from adjoining fields. The application of this method to stone of uniform quality would be detrimental and have the same effect as screening.

386. Binding.—One half of the volume of loosely spread broken stone is space, and no amount of rolling will reduce it more than one half; therefore to thoroughly consolidate the broken stone some fine material must be added. It may consist of the fragments and detritus obtained in crushing the stone. When this is insufficient, as will be the case with the harder rocks, the deficiency may be made up of clean sand or gravel. The proportion of binder should slightly exceed the voids in the aggregate; it must not be mixed with the stones, but should be spread uniformly in small quantities over the surface and rolled into the interstices with the aid of water and brooms.

387. It is a useless refinement to screen the broken stone; it should be placed in the road as it comes from the breakers, care being taken to prevent the admixture of clay or loam, the presence of which in large quantities is extremely injurious. When present to an injurious extent, the stone must be screened.

388. By using a large quantity of binding material mixed with the stones the amount of rolling is lessened, but at the expense of durability. If there is an excess of binding material in the joints of the stones, the first heavy rain washes it out and the surface of the roadway quickly goes to pieces.

389. The French engineers use clay, sand, or earth from the road excavation when such is suitable, in the proportion of one fourth to one sixteenth of the bulk of the stone. They apply it after the steam roller has been once over the broken stones.

390. Necessity of Binding Material.—With reference to the necessity of binding material, the following facts are interesting.

Mr. Wm. H. Grant, Superintending Engineer of the New York Central Park, in his report upon the park roads, says:

"At the commencement of the macadam roads, the experiment was tried of rolling and compacting the stone by a strict adherence to Macadam's theory, that of carefully excluding all dirt and foreign material from the stones, and trusting to the action of the roller and the travel of teams to accomplish the work of consolidation. The bottom layer of stone was sufficiently compacted in this way to form and retain, under the action of the rollers (after the compression had reached its practical limit), an even and regular surface; but the top layer, with the use of the heavy roller loaded to its greatest capacity, it was found impracticable to solidify and reduce to such a surface as would prevent the stones from loosening and being displaced by the action of wagon-wheels and horses' feet. No amount of rolling was sufficient to produce a thorough binding upon the stones, or to cause a mechanical union and adjustment of their sides and angles together as to enable them mutually to assist each other in resisting displacement. The rolling was persisted in with the roller adjusted to different weights up to the maximum load (12 tons), until it was apparent that the opposite effect from that intended was being produced. The stones became rounded by the excessive attrition they were subjected to, their more angular parts wearing away, and the weaker and smaller ones being crushed.

"The experiment was not pushed beyond this point. It was conclusively shown that broken stones of the ordinary sizes and of the best quality for wear and durability, with the greatest care and attention to all the necessary conditions of rolling and compression would not consolidate in the effectual manner required for the surface of a road while entirely isolated from and independent of other substances. The utmost efforts to compress and solidify them while in this condition, after a certain limit had been reached, were unavailing."

391. Mr. Deacon, Engineer of Liverpool, England, describes the effect of binding material as follows:

"Under a 15-ton steam roller preceded by a watering-cart, 1200 yards of trap-rock macadam, without binding, can only be moderately consolidated by twenty-seven hours' continuous rolling. If the trap-rock chippings from the stone-breaker are used for binding, the same area may be moderately consolidated by the same roller in eighteen hours. If silicious gravel from $\frac{3}{8}$ inch to the size of a pin's head, mixed with about one fourth part of macadam sweepings obtained in wet weather, be used, the area may be thoroughly consolidated in nine hours.

"Macadam laid according to the last method wears better than that laid by the second, and that laid by the second much better than that laid by the first."

392. Watering.—Wetting the stone expedites the consolidation, decreases crushing under the roller, and assists the filling of the voids with the binder. It should be applied by a sprinkler and not be thrown on in quantity or from the plain nozzle of a hose.

Excessive watering, especially in the earlier stages, tends to soften the foundation, and care should be exercised in its application.

393. Compacting the Broken Stone.—Three methods of compacting the broken stone are practised: (1) by the traffic passing over the road; (2) by rollers drawn by horses; (3) by rollers propelled by steam.

394. The first method is both defective and objectionable. (1) It is destructive to the horses and vehicles using the road. (2) It is wasteful of material; about one third of the stone is worn away in the operation. (3) Dung and dust are ground up with the stone, and the road is more readily affected by wet and frost.

395. The first recorded allusion to the consolidation of roads

by rolling seems to have been made in 1619 by John Shotbolt in England. The first practical application of rollers appears to have been made by the French engineers in 1829. Their first application in England appears to have been made by Sir John E. Burgoyne. Since these dates rolling has been universally adopted on the continent of Europe, not as a refinement but as a necessity, and no road is considered complete until it has been thoroughly compacted by a roller.

396. Advantages of Rolling.—The advantage of rolling broken-stone pavement may be summed up as follows:

(1) The saving of wear and tear of horses and vehicles. Roads should be made for the traffic and not by it.

(2) Comfort of persons using the roads.

(3) Economy, as a saving of from 30 to 50 per cent is effected by reason of the roads being better made, thus obviating the necessity for such frequent sweeping and scraping. If a portion of a road that has not been rolled is broken up and the material washed, it will be found that as much as half of it is soluble matter, mud, dirt, and fine sand. The stones having been thrown loosely upon the road-bed have lain so long before becoming consolidated by the traffic, and have undergone in the mean time such extensive abrasion, that the proportion of mud, dirt, and pulverized material is increased to that extent, and the stones are really only stuck together by the mud. This accounts for the fact that although an unrolled road may indeed after long use have a surface that is pretty good and hard in dry weather, and may offer then a very slight resistance to traction, yet it will quickly become soft and muddy when there is rain. By the employment of a roller of competent weight the stones are well bedded at once, and the surface is consolidated into a sort of stone felt capable of resisting most effectually the action of the traffic, and containing the smallest quantity of soluble matter to form mud in wet weather.

(4) The avoidance of cruelty to horses, as in the case of newly metalled unrolled roads.

397. Horse Rollers.—Rollers drawn by horses are unsatisfactory for compacting the broken stone. They are expensive to use, requiring a large number of horses and attendants. The horses' feet displace as many stones as the roller compacts, and if they are of great weight they become clumsy and difficult of manipulation.

398. Steam Rollers.—Steam rollers were first introduced in 1860, since which time they have been almost universally adopted on account of the superiority and economy of the work done. They are simply a locomotive mounted on broad and heavy wheels. They can be made of any desired weight. Those now in use vary from eight to thirty tons. Ten tons appears to be the most desirable weight. Heavier rollers are unwieldy, and from their great weight are liable to damage the sewers, water, or other underground service-pipes that may be in the roadway.

399. The advantages of steam rolling may be summed up as follows:

(1) They shorten the time of construction.

(2) A saving of road metal, (*a*) because there are no loose stones to be kicked about and worn; (*b*) because there is no abrasion of the stones, only one surface of the stone being exposed to wear; (*c*) because a thinner coating of stone can be employed; (*d*) because no ruts can be formed in which water can lie to rot the stone.

(3) Steam-rolled roads are easier to travel on account of their even surface and superior hardness and have a better appearance.

(4) The roads can be repaired at any season of the year.

(5) Saving both in materials and manual labor.

400. Form of Rollers.—The advantage of the present form of rollers is generally overestimated. The heaviest roller in use does not exert the same pressure per inch of width nor in the same manner that a heavily loaded wagon does. An ordinary cart, loaded, presses with a weight of about 1000 pounds per inch width of tire; a loaded four-wheeled wagon exerts a pressure of about 850 pounds per inch, and a 10-ton roller about 450 pounds: so that as far as the surface of the roadway is concerned the roller affects it the least of any of the above loads. Therefore a roller should be as heavy per inch of width as a loaded wagon-wheel is per inch of tire, else the wagon-wheels will exercise more pressure per inch, and consequently will cut into the rolled surface and produce ruts.

The wheels of the rollers now in use have too wide a bearing on the road surface. The smaller soft spots are bridged over and remain unseen until the road is completed and thrown open for use. The traffic will quickly find these soft spots, and hollows and ruts will form. To obviate this and obtain the best effect from rollers, they should be constructed with both front and rear rolls. The front roll

should be formed of disks, having diameters varying about six inches, set alternately on the axle. The rear roll may be formed of two or more disks of uniform diameter. The ridges left by the front roll will be levelled by the rear roll. The effect produced by a roller of this form will approximate more nearly the effect of loaded wagon-wheels.

401. The driving rolls of steam-rollers usually have holes bored in their faces to receive spikes, in order that they may be used for breaking up or disintegrating the road-surface. These, however, apparently do not answer; the working of a machine in this manner shakes and strains it considerably, and the holes in the rollers, which are plugged with wood when not in use for this purpose, are objectionable; the plugs wear out and the road metal gets into holes, and the surface of the road is picked up as the rolling proceeds. Besides this, the spikes seem to have no effect unless the surface of the roadway being operated upon is soft.

402. The steepest gradient upon which a steam roller can be operated appears to be 1 in 6, but this requires a very heavy pressure of steam; 1 in 14 or about 7% seems to give no trouble in rolling either up or down.

403. Cost of Maintaining Steam Rollers.—The annual cost of maintaining steam rollers as given in the reports of city engineers is as follows:

HARTFORD, CONN.

One 10-ton roller	$4,000.00	
Wages of engineer and tenders		$888.57
Coal (40,730 pounds)		111.01
Wood ($5\frac{1}{2}$ cords)		31.20
Water for boiler		12.00
Repairs, tools, etc		210.70
Oil, waste, and packing		43.59
Insurance		15.00
Total for year		$1,312.07

TOLEDO, OHIO.

Wages	$951.50
Fuel, supplies, and repairs	316.29
Total for year	$1,267.79

DULUTH, MINN.

Wages, fuel, repairs, etc	$2,087.41

In England the cost per annum for 9 hours per day is about $2000.

404. Amount of Rolling.—The number of superficial yards rolled per day must vary extremely with circumstances—the class of material, the amount of binding and water used, the gradient and pressure of steam maintained, and the amount of rolling considered necessary. The number of square yards rolled varies from 500 to 3000 per diem, the average of 42 English towns being 1105 square yards per diem.

In Paris 2 to 3.75 ton-miles of roller are applied to every cubic yard of stone. The weight of steam rollers per inch of run is specified to be 448 and 336 pounds, and for horse rollers 263 pounds. The ton-miles necessary to make a square yard of porphyry wheel-way, or to compact a cubic yard of the same metal, is given as follows: The mean for two models of machines weighing 448 pounds per inch run was, per square yard, with the thickness of 3.9 inches, 0.41 ton-mile; while for the roller of 336 pounds, with a thickness of 2.8 inches, 0.234 ton-mile was required, or 3.78 and 2.99 ton-miles per cubic yard respectively; and for horse rollers, where the thickness was 2.6 inches, the ton-miles required were 0.194 per square yard and 2.69 per cubic yard. The amounts consolidated per ton per hour are in the following proportions: 467 for the heavy rollers, 539 for the light rollers, and 297 for the horse roller, and the number of passages of the rollers were 98.5, 75, and 92. The maximum speed is stated at 2.3 miles per hour. The rolling is done by contract (the city furnishing the water) at a rate per ton-mile varying from 15.26 to 7.63 cents, according to the amount, with an increase of one third in price where the grade exceeds 6 per cent.

The Southern Boulevard, New York City, constructed by Mr. E. P. North, received 0.859 ton-mile per square yard or 5.177 ton-miles per cubic yard.

From careful experiments with blue limestone in England, it has been found that to obtain consolidation with the usual coating of two stones in thickness (each cubic yard broken to 2½-inch gauge, and made to cover about 17 square yards of surface), the steam roller must traverse a patch equal to its own width about 35 times. From this it appears that a cubic yard of broken stone requires 1½ ton-miles to produce consolidation. For binding about

5 per cent. of well-weathered road-scraping was used, being spread over the surface when consolidation was nearly effected. Without the use of binding, consolidation was found impossible.

The only guide for the proper amount of rolling is that it must be continued until the stones cease to creep in front or sink under the rolls, and the surface has become smooth and firm.

405. Manner of Applying the Roller.—The stone should be spread in a uniform layer 4½ inches thick. This depth will consolidate better than either thicker or thinner. Commence the rolling at the sides, and continue it until such a degree of firmness is attained that when the roller passes over the centre or crown of the road, its weight, which tends to spread the metal or make it work off towards the sides, may be resisted by their consolidation.

The surface of a well-constructed broken-stone road should, after being rolled, look almost like an encaustic pavement.

The rolling should be done slowly, as nothing is gained by a rapid motion; the fuel consumption being considerably increased without any advantage to the work.

406. Cost of Rolling.—The average cost of rolling varies considerably by reason of the amount of rolling considered necessary. In England it varies between one and two cents per square yard. In the United States it varies between 0.015 to 14 cents per square yard.

407. Cost of Broken-stone Pavement.—What the cost of broken-stone pavements will be must depend upon the accessibility and

TABLE XLI.

COST OF BROKEN-STONE ROADS.

Locality.	Thickness of Stone. Inches.	Width of Pavement. Feet.	Method.	Cost per Mile.
Bridgeport, Conn.	4	18 to 20	Macadam	$3,000
Fairfield, Conn.	4	20	Macadam	5,000
Fanwood, Conn.	12	16	Telford	9,530
Franklin Township, N. J.	4	15	Macadam	4,700
Kingston, R. I.	8	16 to 20	Macadam	5,500
Linden Township, N. J.	12	16	Telford	11,600
Plainfield, N. J.	4 to 6	16	Macadam	3,000
Rahway, N. J.	12	16	Telford	9,349
Westfield, N. J.	12	16	Telford	9,640
Union Township, N. J.	12	16	Telford	11,900

cost of material and labor, which will be quite variable. In Tables XLI and XLII is given the cost in different localities in the United States.

TABLE XLII.

EXTENT AND COST OF BROKEN-STONE PAVEMENTS IN SOME OF THE PRINCIPAL CITIES OF THE UNITED STATES IN 1890.

Cities.	Extent. Miles.	Cost per Square Yard.
St. Louis, Mo	271.76	$0.51
Chicago, Ill	226.67	0.90* to 1.70†
Boston, Mass	172.00	0.75 to 1.25
Nashville, Tenn	111.00	0.45
Providence, R. I	110.00	
Philadelphia, Pa	90.80	
Hartford, Conn	64.00	1.00
Syracuse, N. Y	50.00	0.69 to 1.08
Rochester, N. Y	46.00	1.25
Paterson, N. J	38.00	0.45
New Haven, Conn	28.50	0.50 to 1.25
New York, N. Y	25.34	1.00 to 1.50‡
Worcester, Mass	20.00	
Cambridge, Mass	20.00	0.70
Harrisburg, Pa	20.00	
Toledo, Ohio	10.39	1.23
Burlington, Vt	7.74	
Washington, D. C	6.00	
Richmond, Va	5.72	0.75 §
Utica, N. Y	2.62	
Oswego, N. Y	2.18	
Albany, N. Y	1.71	
Milwaukee, Wis	1.16	
Los Angeles, Cal	1.00	1.17
Schenectady, N. Y	0.75	
Cincinnati, Ohio		1.25 ¶
Duluth, Minn	44.00	
Jersey City, N. J	1.50	
East Saginaw, Mich	1.00	
Springfield, Mass	15.00	
Chelsea, Mass	5.00	
Dubuque, Iowa	34.60	
Toronto, Can	37.27	
Mobile, Ala	20.00	
Lowell, Mass	10.00	
St. Louis, Mo	18.33 ‡	0.84
Newark, N. J	10.84 ‡	1.75
Kingston, N. Y	4.50 ‡	
Toledo, Ohio	1.11 ‡	
Trenton, N. J	0.50 ‡	

* Limestone and gravel 10 inches deep. † Crushed granite topping.
‡ Telford. § 12 inches deep. ¶ 18 inches deep.

408 Difference in the Cost of European and American Broken-stone Pavements.—As an example exhibiting the difference in the cost of constructing macadam roads in Europe and the United States, we select a first-class highway of the broadest type, one which was built about ten years ago over a level expanse between the villages of Langenfeld and Burgwald, Germany. The road in question is 2100 meters (6888 feet) long, 26½ feet in width, the macadamized wagon track 13⅛ feet wide and 8¼ inches thick. With labor estimated at 36 cents per day except for stone masonry, which costs in country districts from 60 to 75 cents per day, the construction account of this road foots up as follows:

	Germany.	America.
Grading roadway	$707.61	$1743.00
Planting and turfing slopes	89.96	268.88
Bridges and culverts	154.70	464.10
Macadamizing	3647.35	7843.50
Milestones, etc.	11.38	34.14
Tools	75.68	151.36
Damages to adjacent property during work	155.65	155.65
Tree-planting	61.88	185.64
Superintendence of construction	369.85	784.35
Incidentals	49.98	49.98
	$5324.04	$11680.00
This is equivalent to about	$4092.00 per mile	$8947.60 per mile

409. Wear of Broken-stone Pavements.—The wear of road materials resulting in their gradual reduction to detritus is due to the joint action of the traffic and the weather. When the wear is confined to the abrasion of the surface, it is the least possible; but when a road is weak from insufficient thickness, or from a yielding foundation, bending and cross-breaking take place under passing loads, and a movement is produced in the body of the road which causes internal wear by the rubbing of the stones against each other; this wear is aggravated by the softening action of water finding its way into the roadbed through cracks in the surface, and by the disintegrating action of frost; the wear and waste are thus far greater than on roads of sufficient strength properly maintained.

410. The relative proportions in which a road is deteriorated by the action of atmospheric changes, wheels, and horses' feet for the generality of roads is approximately as follows:

Atmospheric causes	20	per cent
Wheels	35.5	"
Horses' hoofs	44.5	"

411. The effect of horses' feet is to form depressions which, if not immediately eradicated, prepare the way for further injury by the wheels. Horses moving at a walk and drawing heavily-loaded wagons do far more injury than horses travelling quickly and drawing lightly-loaded vehicles.

412. The quantity of stone worn away annually from the surface of roads is an exceedingly variable quantity, dependent not only upon the character of the stone and the quantity of the traffic, but also upon the mode of maintaining the road. Mud is an excellent assistant in rapidly grinding down the surface. Many attempts have been made to measure the wear on roads, but no definite conclusions can be arrived at.

413. The wear or loss of thickness on some of the heavily travelled streets of London and Paris has been as much as four inches per annum. In Birmingham, England, the macadam streets have worn down six inches in one year under a traffic of 2484 vehicles in ten hours.

The average loss of thickness on the European roads appears not to exceed one inch per year.

414. The amount of material used annually in England to replace the wear on main roads varies from 40 cubic yards per mile in the country districts to 1000, and in some cases to 1500 cubic yards in the vicinity of large towns. The general average appears to be from 70 to 80 cubic yards per mile, the least being 10 cubic yards per mile.

The average annual consumption of broken stone to replace wear in France and Austria appears to be about 70 cubic yards per mile.

415. The loss of thickness by wear should be restored annually by spreading coats of two or more stones thick and consolidating it with the roller. Before applying the coating the surface of the road should be broken up with picks in cross-courses about 4 inches apart; the depth to which the surface is broken should not exceed

2 inches. Steam rollers are furnished with picks for this purpose, but their employment is not satisfactory or advantageous; if the spikes are short, they have no effect on the road unless it is soft; if they are long, they penetrate the body of the road, breaking the bond, and leave the road a mass of loose stones. Besides the employment of the roller for this purpose shakes and strains it considerably.

416. The practice of spreading the new coating and leaving it to be consolidated by the traffic is open to the same objections as the construction of unrolled roads. It is an obstacle instead of an aid to traffic.

When the stone is spread, the sooner it is rolled solid the better.

417. Recoating the road should be done at that season of the year which will interfere the least with the movement of the traffic. Wet or damp weather is most suitable, but when water is obtainable it may be done at any season.

418. Cost of Maintenance.—The cost of maintaining broken-stone pavements varies between very wide limits. A road with little traffic, well drained, and exposed to the sun and air, with fairly good materials at hand, can be kept in repair at a very small yearly cost, while a suburban or city street may cost several hundred dollars. Unless the amount of the traffic, the quantity of materials used, their price, and other particulars be taken into account, the cost per mile or square yard at which a road is maintained affords little real information, and may be misleading.

In London the cost of maintaining macadam pavements is stated as follows:

In heavy-traffic streets	62½	cts. per sq. yd.
In moderate-traffic streets	29¾	"
In light- " "	14½	"
In lightest- " "	6¼	"

In Paris macadam costs about 45 cents per square yard per year. In Boston, Mass., about 50 cents.

The cost of maintaining the high-roads of Austria ranges from $1032 to $1571 per mile per annum; of these amounts about 50 per cent (49 to 52) is for materials. The highways of Belgium cost between 6 and 10 cents per square yard per year.

The French roads cost from 1 to 10 cents per square yard per year.

The annual cost of maintaining the government roads of Bavaria in 1877 was, per kilometer, or .62 English mile, as follows:

Cost of material	$54.26
Extra labor	11.42
Bridges and culverts	2.52
Retaining-walls and gutters	.31
Road-paving	2.45
Cost of tools	1.02
	$71.98

or about $116.09 per English mile. Total number of men employed on the government roads was 1089. The average cost of regular roadmen per English mile was $45.25.

Total length of government roads:

The total length of government roads macadamized	4,223 miles
" " " " " " paved	29 "
" " " " " " over bridges	6 "
	4,258 miles

419. Descriptions of Modern Broken-stone Roads.—"First-class metropolitan roads, England: The ground is excavated or filled to the required level, then thoroughly consolidated by rolling. On the earth-bed thus prepared a bottoming or bed 12 inches thick, of "hard core," consisting of brick rubbish, clinker, old broken concrete, broken stone or shivers, or any other hard material in pieces, is spread and rolled down to a thickness of 9 inches, and any loose or hollow places made up to the level.

"Next comes a layer of Thames ballast 5 inches thick, rolled solidly to a thickness of 3 inches. The ballast serves to fill up the vacancies in the bottoming, and, being less costly, saves so much of the cost for broken granite."

Broken granite, or macadam, is laid upon the prepared surface of the ballast in two successive layers 3 inches thick, rolled successively to a combined thickness of 4 inches; a layer of sharp sand $\frac{1}{2}$ or $\frac{3}{4}$ inch thick is scattered over the second layer, and rolled into it with plenty of water.

420. The method adopted in Chicago is as follows: The roadbed is prepared to the required contour and well consolidated with a

steam roller. On this surface rubble-stone is carefully placed by hand, with its broadest side downwards, then 12 inches of broken stone are spread, 6 inches at a time, thoroughly rolled, to bond it; it is then topped with 4 inches of crushed trap or other equally hard rock; this is again thoroughly rolled, so as to compact and bind it together.

421. The method adopted in the construction of the Bridgeport, Conn., roads is as follows: The ground is graded and regulated with a gutter 18 inches deep on each side; the soil is then thoroughly rolled with a 15-ton roller, and the stone spread on the surface so prepared. Three varieties of soil are met with in Bridgeport: (1) a fine "dead" sand, which sometimes cannot be rolled on account of its pushing before the roller, without covering it with coarse broken stone—this expedient, acting as a pavement, prevents movement; (2) loam, and (3) a hard-pan with mica disseminated through it. Underdraining has in no case been resorted to, the 18-inch gutters being depended on for drainage. After the broken trap-rock is rolled to a bearing, screenings are added as a binder and the road metal is well and thoroughly filled with them, the whole being rolled until the water flushes on the surface. A strong silicious sand is sometimes used, in part, in place of screenings, and when, in dry weather, the road commences to break up or "ravel," out of easy access by watering-carts, sand is spread over the spot, which quickly consolidates the road. No loam or clay is used as a binder or filler in the construction of the roads, nor in their repair, except when the surface over a ditch is to be replaced and it is too small a patch to justify bringing the roller; then the broken trap is laid down after being mixed with the proper quantity of screenings, and the whole covered with loam. The traffic consolidates it in a short time.

It should be noticed, in connection with the low cost of those roads stated in Table XLII,—about 28 cents per square yard,—that Bridgeport, in addition to the possession of particularly good trap-rock, is exceptionally favored in the location of its quarry—almost exactly two miles from the centre of the city; so that the cost of the stone is 82 cents per gross ton of 21 or 22 cubic feet, delivered to the wagons; and the cost of hauling varies, depending on the distance, from 50 to 75 cents per ton, or between $1.32 and $1.57 per gross ton delivered on the road. The trap-rock is broken to 2-

inch size by three 7 × 10-inch Marsden crushers, placed side by side on a platform, to which cars are drawn from the quarry by a wire rope, wound by the same engine which runs the crushers. The interest on the cost of the roller—an Aveling & Porter, now twenty years old—is not reckoned in the above-mentioned cost.

That the cost of the Bridgeport roads has not been underestimated is apparently made certain by the contract price of such work in the neighboring town of Fairfield, where, with a longer haul, a 4-inch road 20 feet wide was built for 85 cents per lineal foot or 38.3 cents per square foot. This sum included regulating, some grading, and the use of a roller, as well as the contractor's profit.

422. Extracts from Specifications for forming Telford Roads in St. Louis, Mo.

Drainage.—All drains considered necessary by the Street Commissioner to carry off the water shall, when required, be made by the contractor for the work, and shall be paid for at a price agreed upon by the Street Commissioner.

Sub-foundation.—After the curbstones are set, the second grading and shaping of the roadway shall be done. All surplus earth and other material shall be removed and the sub-foundation formed to a depth of eighteen (18) inches below the intended surface of the street, the cross-section thereof to conform in every respect to the cross-section of the pavement when finished. The roadbed shall then be rolled with a roller weighing not less than five (5) tons, when required by the Street Commissioner. All depressions which may appear shall be carefully refilled before any stone is put on.

Lower Course of Telford.—When the street shall be thus graded and formed, a bottom course or layer of limestone of approved quality shall be laid by hand in regular straight courses at right angles with the line of the streets, so as to break joints; the bottom surfaces of the stones shall form as close joints as possible. The stones to be used shall not be less than three (3) inches nor more than eight (8) inches thick, and from five (5) to ten (10) inches long on their bottom surfaces, and must be thoroughly settled to place with hammers. The interstices shall then be filled with stone chips firmly wedged by hand with hammers, and all projecting points shall be broken off. The tops of the stones when levelled off shall have a surface not greater than one third of the

base. The foundation or bottom course when finished shall have a regular and uniform depth of not less than seven (7) inches. The bottom course along the curb and under the gutter for a width of four (4) feet, and under the cross-walk for a width of eight (8) feet, shall be thoroughly consolidated by rolling or ramming, and the surface be made even by filling the spaces between the stones with sand in such manner as the Street Commissioner may direct.

Guttering.—After the Telford foundation has been prepared the gutter shall be put down upon a bed of clean coarse sand at least two (2) inches deep. The paving-blocks shall be from six (6) to seven (7) inches deep, four (4) to six (6) inches thick, and eight (8) to twelve (12) inches long. The faces shall be straight, free from bunches, depressions, and inequalities exceeding one half (½) inch. The faces shall meet at right angles, and the corresponding dimensions of opposite faces shall not vary more than one-half (½) inch. They must be set vertically on edge, in close contact with each other, in straight rows at right angles with the curb, the blocks in different rows breaking joint by a space not less than four (4) inches. The joints between the blocks shall be filled with clean, sharp sand.

Cross-gutters.—The cross-gutters shall be of such width and shape as may be directed. The stone used therefor shall be from three (3) to six (6) inches thick, nine (9) inches deep, and from six (6) to twelve (12) inches long. The bottom course of stone shall be eight (8) inches thick, nine (9) inches deep, and not less than twelve (12) inches long.

Quality and Finish of Stone Work.—All stones used for gutters, cross-gutters, and cross-walks shall be limestone of the best quality, from ledges known to withstand the effects of frost, and free from seams and all other defects. All paving-stone shall be dressed so as to make close joints at least four (4) inches deep, and have a square bottom not less than three quarters (¾) of the superficial surface of the top of the same stone. All materials shall be fully dressed before they are brought onto the street to be improved. The whole paving must be made tight, compact and smooth, and be fully fed with sand, and must be laid true and uniform, with broken joints, and have a full bond of at least four (4) inches. After the paving is laid it must be sanded on top, the sand

TYPE-SECTIONS OF BROKEN-STONE PAVEMENTS.

Fig. 25.

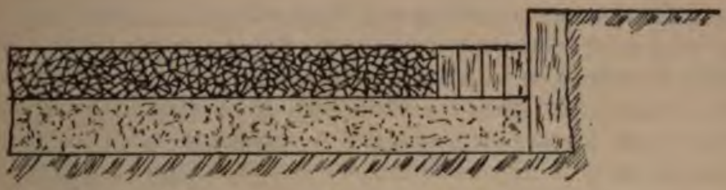


Fig. 26.

Fig. 27.

Fig. 28.

swept into the joints with a broom, and be settled down evenly and firmly with a rammer of not less than forty (40) pounds weight.

Macadam or Second Course.—When the Telford foundation has thus been formed, there shall be placed thereon a layer of clean, hard limestone macadam, free from clay, earth, rubbish, or other foreign matter, so broken that the largest pieces shall pass through a two and one half ($2\frac{1}{2}$) inch ring in all their dimensions, and shall be fully broken before it is brought on the line of work. This course shall have such a depth and form of cross-section as may be directed by the Street Commissioner, and shall be thoroughly consolidated by rolling with a roller weighing not less than five (5) tons.

Sand.—The macadam course having been finished, the spaces between the stones shall be well filled with clean, coarse sand, or so much sand as may be directed by the Street Commissioner, which shall be washed in with water from a hose having a rose attached to the nozzle, and then the whole shall be rerolled to the satisfaction of the Street Commissioner. A sprinkling-cart shall not be used unless it is impossible to make a connection with a fire-plug, and then only with the consent of the Street Commissioner. A water license and a permit from the Water Commissioner must first be obtained before a fire-plug can be opened.

Gravel.—The macadam course with binding material having been finished, there shall be placed thereon a layer of good clean gravel, free from clay, animal, or vegetable matter, and containing not more than fifteen (15) per cent of loam or sand, nor shall the largest pebbles exceed one inch in diameter; to be well wetted down or slushed with water and thoroughly rolled to a perfect surface, having such form of cross-section and depth as may be directed by the Street Commissioner.

423. Heads of Specifications for Broken-stone Pavements.

(1) Preparation of roadbed.

(2) Foundation (sand, gravel, etc.).

(3) Quality of the stone.

(4) Size of the stone.

(5) Cleanness of the stone. (The stone must at all times be clean and free from clay or other dirt.)

(6) Spreading the stone.

(7) Thickness of layers.

(8) Rolling: weight of roller and amount of rolling.

(9) Watering.
(10) Binding, quality and quantity of.
(11) Interpretation of specifications.
(12) Omissions in specifications.
(13) Engineer defined.
(14) Contractor defined.
(15) Notice to contractors, how served.
(16) Preservation of engineer's marks, etc.
(17) Dismissal of incompetent persons.
(18) Quality of materials.
(19) Samples.
(20) Inspectors.
(21) Defective work, responsibility for.
(22) Measurements.
(23) Partial payments.
(24) Commencement of work.
(25) Time of completion.
(26) Forfeiture of contract.
(27) Damages for non-completion.
(28) Evidence of the payment of claims.
(29) Protection of persons and property.
(30) Indemnity bond.
(31) Bond for faithful performance of work.
(32) Power to suspend work.
(33) Right to construct sewers, etc.
(34) Loss and damage.
(35) Old materials, disposal of.
(36) Cleaning up.
(37) Personal attention of contractor.
(38) Payment of workmen.
(39) Prices.
(40) Security retained for repairs.
(41) Payment, when made. Final acceptance.

CHAPTER VIII.

MISCELLANEOUS PAVEMENTS.

424. Gravel Roads.—Gravel, though not as durable as broken stone, has proved very serviceable as a road covering.

In selecting gravel for this purpose, the chief quality to be sought for is the property of binding. The binding properties are two: the presence of ferruginous clay, which causes the gravel to set or become hard as soon as it is exposed to the action of the atmosphere; and the angular shapes and sizes of the stones.

425. Gravel from the sea-beach and shores of rivers, and that in which the stones are round or oval, with regular smooth surfaces, never forms a good binding material, even if mixed with ferruginous clay. The reason is that the stones which are on the surface have no mechanical hold on those which are beneath or beside them, but being merely cemented by means of the clay they are easily loosened and thrown out of place by the action of the traffic or frost, and even by the alternate actions of drought and moisture.

426. When no gravel but that found in rivers or on the sea-shore can be obtained, one-half of the stones should be broken and mixed with the other half; to the stone so mixed a small quantity of clay or loam, about one-eighth of the bulk of the gravel, must be added: an excess is injurious. Sand is unsuitable: it prevents packing in proportion to the amount added.

427. Preparing the Gravel.—Pit-gravel usually contains too much earth, and should be screened before being used. Two sieves should be provided,—one with meshes of one and one-half inches, so that all pebbles above that size may be rejected, the other with meshes of three quarters of an inch, and the material which passes through it should be thrown away. The expense of screening will be more than repaid by the superior condition of the road formed

by the cleaned material, and the diminution of labor in keeping it in order. The pebbles larger than one and a half inches may be broken to that size and mixed with the cleaned material.

428. Laying the Gravel.—On the roadbed properly prepared a layer of the prepared gravel four inches thick is uniformly spread over the whole width, then compacted with a roller weighing not less than two tons, and having a length of not less than thirty inches. The rolling must be continued until the pebbles ceases to rise or creep in front of the roller. The surface must be moistened by sprinkling in advance of the roller, but too much water must not be used. Successive layers follow, each being treated in the above-described manner until the requisite depth and form has been attained.

429. The gravel in the bottom layer must be no larger than that in the top layer; it must be uniformly mixed, large and small together, for if not so the vibration of the traffic and the action of frost will cause the larger pebbles to rise to the surface and the smaller ones to descend, like the materials in a shaken sieve, and the road will never be smooth or firm.

The pebbles in a gravel road are simply imbedded in a paste and can be easily displaced. It is for this reason, among others, that such roads are subject to internal destruction.

430. The binding power of clay depends in a large measure upon the state of the weather. During rainy periods a gravel road becomes soft and muddy, while in very dry weather the clay will contract and crack, thus releasing the pebbles, and giving a loose surface. The most favorable conditions are obtained in moderately damp or dry weather, during which a gravel road offers several advantages for light traffic, the character of the drainage, etc., largely determining durability, cost, maintenance, etc.

431. Repair.—Gravel roads constructed as above described will need but little repairs for some years, but daily attention is required to make these. A garden rake should be kept at hand to draw any loose gravel into the wheel-tracks, and for filling any depressions that may occur.

In making repairs, it is best to apply a small quantity of gravel at a time, unless it is a spot which has actually cut through. Two inches of gravel at once is more profitable than a larger amount. Where thick coating is applied at once it does not all pack, and if,

after the surface is solid, a cut be made, loose gravel will be found; this holds water and makes the road heave and become spouty under the action of frost. It will cost no more to apply six inches of gravel at three different times than to do it all at once.

At every one-eighth of a mile a few cubic yards of gravel should be stored, to be used in filling depressions and ruts as fast as they appear, and there should be at least one laborer to every five miles of road.

432. Cost of Construction in Illinois.—The cost has been about $900 per mile for a roadway 12 feet wide, 12 inches deep at the centre and 9 inches at the sides.

Table XLIII shows the extent and cost of gravel pavements in some of the principal cities in the United States.

TABLE XLIII.

EXTENT AND COST OF GRAVEL PAVEMENTS IN SOME OF THE PRINCIPAL CITIES OF THE UNITED STATES.

Cities.	Extent. Miles.	Cost of Construction per square yard.
Boston, Mass	160.00	$0.75
Cambridge, Mass	67.91	
Richmond, Va	46.44	$0.15 to $0.20
Washington, D. C	33.50	
Grand Rapids, Mich	32.37	
Burlington, Vt.	11.92	
Haverhill, Mass		$0.25

433. Weight of Gravel.—A cubic yard of pit gravel weighs about 3300 pounds. When the distance is not greater than 1½ miles, a team will haul about 7 cubic yards a day; even with hauls of six miles the work can be done at reasonable cost.

434. Bituminous Macadam.—In some towns in England bituminous or asphalt macadamized roadways are made. This consists in mixing ordinary coal-tar with the road metal ordinarily employed for macadamized roads; only it must be borne in mind that the metal employed must be limestone or some other soft material, otherwise it will not wear down evenly with the tar, and thus a lumpy surface will be produced in course of time.

The method of mixing is by heating the stone, which has of course been previously broken to the required size, and then thor-

oughly mixing and incorporating it with the tar. This is carried to the roadway, is spread in the ordinary manner, and well rolled to the proper contour, a surface being afterwards given to it by a coating of about 2 inches thick, composed of a similar mixture, the stones of which are of much smaller size.

Another method is to place about 6 inches of the broken stone upon the necessary foundation. Upon this a boiling mixture, composed of about 50 gallons of creosote oil and 1 ton of pitch, is poured until every interstice is filled with the mixture. Whilst this is still warm, a thin layer of small broken stone is spread upon the surface and well rolled; more small stones or chippings are added, and the whole is rolled until the surface of the roadway has attained its proper contour and presents a perfectly smooth and clean appearance, little inferior to that of real asphalt.

Dry weather is essential whilst this class of roadway is in course of construction, and careful watching is required, as when the skin breaks the whole roadway soon disintegrates. This class of pavement has, however, many advantages over ordinary macadamized roadways when finished, not the least of them being imperviousness to moisture, and the ease with which it may be cleaned.

435. In repairing some of the macadam roads and pavements in Paris, fragments of old asphalt were mixed with the broken stone. The results, as regards wearing qualities, show little improvement over the unmixed stone, but such a pavement keeps remarkably clean during dry weather and does not become as muddy as the true macadam during rainy seasons.

In the middle of summer an unpleasant odor is given out, and the surface has a dirty black color.

436. Concrete Macadam, introduced by Mr. J. Mitchell, London Eng., is composed of broken stone, sand, and Portland cement so proportioned that the spaces, otherwise vacant, and ultimately filled with muddy cementing matter of worn macadam, are filled with an admixture of Portland cement or other hydraulic cement-grout. The concrete thus formed rapidly becomes a uniform and impervious mass which is wholly unaffected by heat or moisture. It is mixed in these proportions:

Broken stones	4	measures
Clean, sharp sand	$1\frac{1}{4}$ to $1\frac{1}{2}$	"
Portland cement	1	"

So for a cubic yard, or 27 cubic feet, of broken metal $6\frac{3}{4}$ cubic feet, or $1\frac{1}{4}$ barrels (of $4\frac{1}{2}$ cubic feet), of Portland cement are required. The broken stone should be of the hardest quality, of uniform size, thoroughly screened; and it should be thoroughly wetted before being incorporated with the cement.

Cement of the best quality must be employed, and the sand should be sharp, clean, and gritty. The surface of the ground is brought to form, and rolled several times. The concrete is then laid on the surface in a layer 3 or 4 inches, and is left for three days to harden. The second layer of 3 or 4 inches is next laid on the first, and immediately rolled to form with a heavy iron roller, as heavy as two or three men can draw. The cement should be left for three weeks, to allow it to become quite hard before the road is opened for traffic, although a week has been found to be a sufficient interval.

Mr. Mitchell states that a concrete road, 7 inches deep at the middle and 5 inches at the sides, is sufficient for ordinary traffic. For heavy traffic a depth of 8 inches is recommended.

The first piece of concrete road was laid in 1865 in Inverness, and consisted of 45 lineal yards of the approach to the freight station of the railway. In 1870, after the road had been under traffic for $4\frac{1}{2}$ years, it was reported that the wear of the surface was scarcely appreciable, whilst the adjoining macadamized road had been coated frequently every year.

Another specimen, 50 yards long and 15 yards wide, was laid in 1866, on George IV. Bridge, Edinburgh, where the traffic is heavy and continuous. At the end of three years and a half under traffic the surface was perfectly sound and immovable.

The amount of vertical wear during the periods above named appears not to have exceeded $\frac{1}{4}$ inch. But Mr. J. H. Cunningham, writing in January, 1875, stated that it was then much worn at the surface, in consequence, he thought, of its great hardness and rigidity.

437. Stone Trackways (Figs. 29 to 32).—Trackways formed of stone slabs were first employed by the Egyptians for moving great weights. In modern times they reappeared in northern Italy, where they are in general use not only in the streets of the principal cities, but also in the smaller towns.

Telford employed a stone trackway on the Holyhead Road to

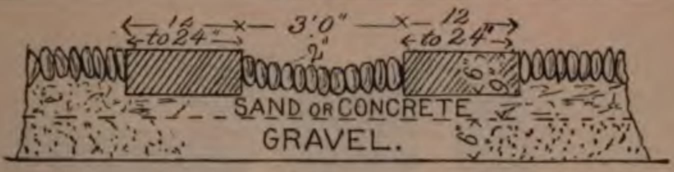


Fig. 29. SECTION OF STONE TRACKWAY

Fig. 30. PLAN OF TRACKWAY

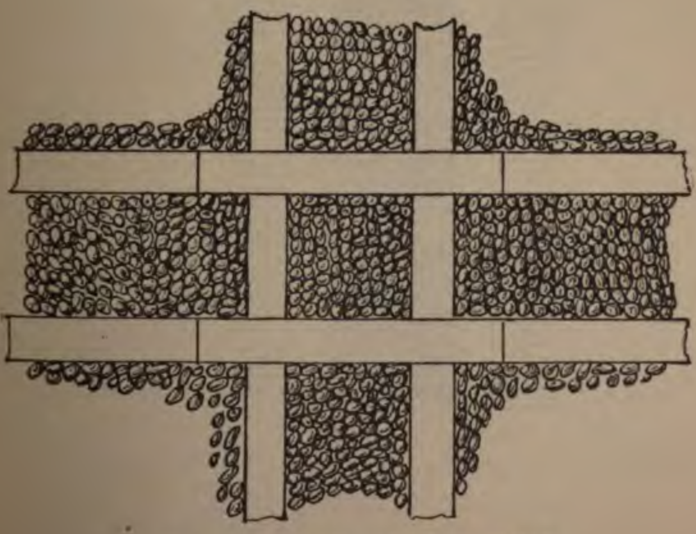


FIG. 31.—PLAN OF CROSSING.

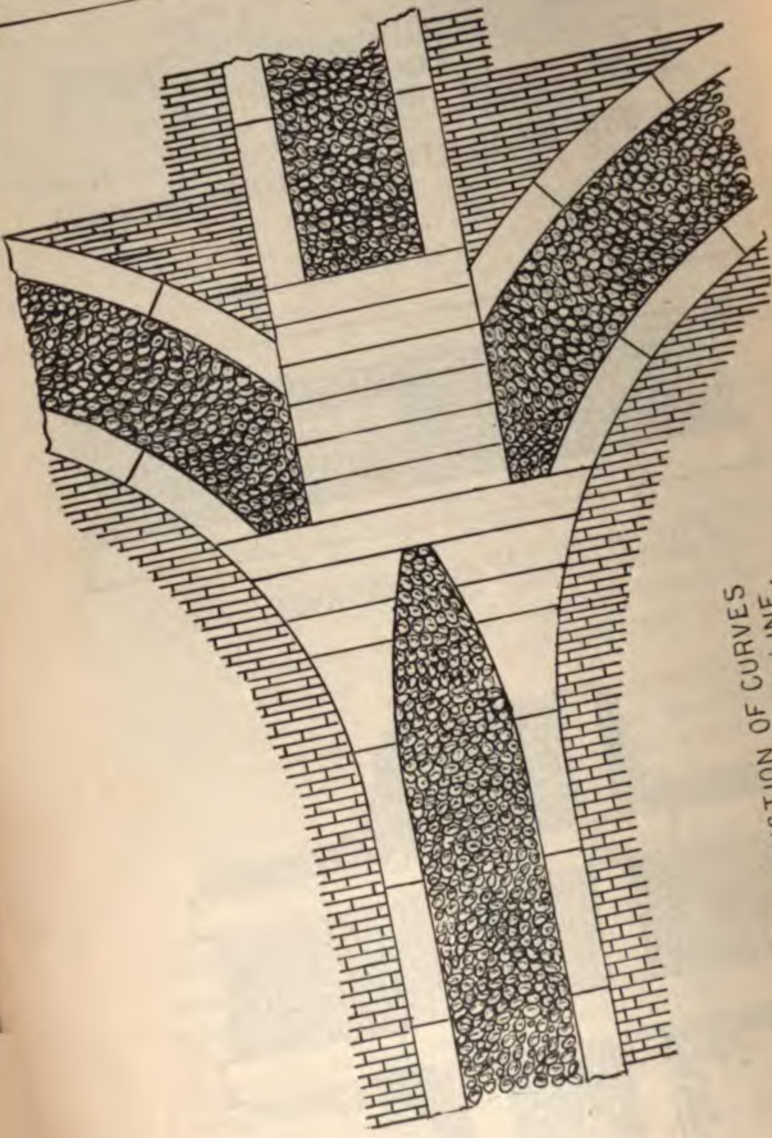


Fig 32. JUNCTION OF CURVES WITH STRAIGHT LINE.

avoid excessive work of construction. There were two hills each a mile in length, with an inclination of 5 : 100. To reduce this to a $4\frac{1}{2}$ per cent grade would have cost $100,000, but nearly the same advantage in diminishing the amount of tractive force required was obtained by making stone trackways at a total expense of one half the former amount and retaining the 5 per cent grade with moderate cutting and embankment. To draw one ton over the original hills required a tractive force of 294 pounds; to draw the same load over the trackways laid on the same inclinations required only 132 pounds.

Trackways of both stone and iron have been used in London, Liverpool, Manchester, Glasgow, and other cities.

438. The Italian trackways consist of two parallel lines of granite blocks, usually 14 inches wide, 8 inches deep, and 5 feet in length, bedded in a layer of sand. The lines are 28 inches apart, and the interspace, or footway for horses, as well as the other portions of the roadway, is paved with cobbles obtained from the Po, or from other rivers. These stones should be egg-shaped, with a maximum diameter of from $3\frac{1}{2}$ to $4\frac{1}{2}$ inches and a depth of from $4\frac{1}{2}$ to $5\frac{1}{2}$ inches. The roadway is usually formed with a slight inclination downwards towards the centre. By this arrangement the space between the trams serves as a channel to receive the surface-water, and is provided with stone gratings, placed at suitable intervals, by which the water escapes into the sewers. The surfaces of the trams are slightly inclined towards each other, the inner edges being $\frac{3}{8}$ inch lower than the outer edges; whilst the interspace is concave, having a versed sine or depression of $1\frac{1}{2}$ inches. The foundation of the roadway consists of a layer of screened gravel, about 6 inches deep, watered so as to form a compact mass. Two inches of sand is laid on the gravel, as a bed for the paving-stones. The upper surfaces of the trams are dressed flat and the ends square, to form close joints. The stone gratings for the gulleys are 32 inches long, formed with three slots 12 inches long and $1\frac{1}{2}$ inches wide. After the trams are placed, the other portions of the pavement are completed. After the surface has been well rammed with a wooden rammer, it is watered and covered with a bedding of sand $\frac{3}{4}$ inch deep, so as to fill the joints by degrees. On steep gradients the surfaces of the trams are grooved diagonally.

439. Trackways are expensive to construct (cost about $14,000

per mile for two lines of track and intermediate paving in the neighborhood of New York), but cost little for repairs and maintenance. Their advantages are many: they combine the opposite qualities required for easy haulage, viz., a smooth surface for the wheels, on which the friction is reduced to the least possible amount, and a rough footway, affording a firm foothold for horses, thus enabling them to exert their utmost tractive power. For this reason they ought to receive more attention than is now accorded them. The friction of their surface is only about $\frac{1}{130}$ of the load, or about one half that of the best block pavement. It is stated that on such trackways in London a horse weighing about 700 pounds could draw on a level 15 tons, and a horse weighing about 1600 pounds could draw $30\frac{1}{2}$ tons.

440. In Glasgow, Scotland, there was a trackway down for forty years. It consisted of cast-iron plates 2 inches thick, 8 inches wide, and cast in lengths of 3 feet. It was laid in Buchanan Street on a 5 per cent grade.

441. The trackways for the wheels may be of granite, or compact sandstone slabs 12 to 24 inches wide, 6 inches thick, and in lengths of 2 to 6 feet. The footway for the horses to be in all cases paved with cobblestones the other portions of the roadway may be paved with cobblestones, granite, or other pavement.

The foundation for the trackways should be constructed as shown in Fig. 29, with all the joints filled with asphaltic paving-cement.

The roadway may be formed in the usual manner with the trackways level (transversely), the surface falling from their outer edge to the gutters; but at frequent intervals in the horse-path catch-basins with iron or stone covers should be placed, connecting with the sewer. At track-crossings or junctions the surface of the slabs should be grooved, so as to afford good foothold for the horses passing over them.

442. "Jasperite."—Jasperite, under what is known as "Drake's Patent," consists of quartzite crushed to sizes of $\frac{1}{2}$, $\frac{1}{4}$, and $\frac{1}{8}$ of an inch, and known as Nos. 3, 4, and 5, respectively. The foundation is composed of irregularly broken stone set to form a rough pavement similar to that used for a Telford road. On this is spread a layer of concrete $1\frac{1}{2}$ inches thick, composed as follows: 1 part of Portland cement, 1 part of sand, and 3 parts of quartzite of the sizes Nos. 3 and 4. This is well mixed, spread, and rammed into

place in such a manner as to form blocks one yard square. These blocks are separated by tarred paper. On the bed so formed is spread a layer one-half inch in thickness, prepared in the same way, but substituting quartzite of the size known as No. 5. This pavement is in use in Sioux Falls, S. D., and Wichita, Kan. The cost per square yard is about $2.50, with a five-year guarantee.

443. **Artificial Granite Blocks** are formed from the chippings of granite quarries. It is mixed at the place where it is to be used with Portland cement in sufficient quantity to make a thorough bond between the pieces, and put down in blocks or squares so as to form separate stones as it were. Its surface is kept comparatively rough by the cement wearing below the points of the granite. Its advantage is, presumably, cheapness.

444. **Plank Roads.**—In localities where timber is abundant and other materials are unobtainable, planks may be employed to form pavements. When new and well laid they form a comfortable carriageway both for haulage and pleasure, but make when worn and displaced a very disagreeable road.

445. The method most generally adopted in constructing plank roads consists in laying a flooring or track 8 feet wide, composed of boards from 9 to 12 inches in width and 3 inches in thickness, which rest upon two parallel rows of stringers or sills laid lengthwise in the road and having their centre lines about 4 feet apart or 2 feet from the axis of the road. Sills of various-sized scantling have been used, but experience seems in favor of scantling about 12 inches in width, 4 inches in thickness, and in lengths of not less than 15 to 20 feet. Sills of these dimensions laid flatwise and firmly embedded present a firm and uniform bearing to the boards and distribute the pressure they receive over so great a surface that, if the soil upon which they rest is compact and is kept well drained, there can be but little settling and displacement of the road-surface from the usual loads passing over it. The better to secure this uniform distribution of the pressure, the sills of one row are so laid as to break joints with the other, and to prevent the ends of the sills from yielding the usual precaution is taken to place short sills at the joints, either beneath the main sills or on the same level with them.

The boards are laid perpendicular to the axis of the road, experience having shown that this position is more favorable to their

wear and tear than any other, and is besides the most economical. Their ends are not in an unbroken line, but so arranged that the ends of every three or four project alternately, on each side of the axis of the road, 3 or 4 inches beyond those next to them, for the purpose of presenting a short shoulder to the wheels of vehicles to facilitate their coming upon the plank surface when from any cause they may have turned aside. On some roads the boards have been spiked to the sills, but this is unnecessary, the stability of the boards being best secured by well packing the earth between and around the sills, so as to present a uniform bearing surface to the boards, and by adopting the usual precautions for keeping the sub-soil well drained and preventing any accumulation of rain-water on the surface. The boards for plank roads should be selected from timber free from the usual defects, such as knots and shakes, which would render it unsuitable for ordinary purposes, as durability is an essential element in the economy of this class of road-construction. Boards of 3 inches in thickness offer all the requisites of strength and durability that can be obtained from timber in its ordinary state, in which it is used for plank roads.

Besides the wooden track of 8 feet, an earthen track of 12 feet in width is made, which serves as a summer road for light vehicles and as a turnout for loaded ones. This, with the wooden track, gives a clear road-surface of 20 feet, the least that can be well allowed for a frequented road. It is recommended to lay the wooden track on the right-hand side of the approach of a road to a town or village, for the proper convenience of the rural traffic, as the heavy trade is to the town. The surface of this track receives a cross-slope from the side towards the axis of the road outwards of 1 in 32. The surface of the summer road receives a cross-slope in the opposite direction of 1 in 16. These slopes are given for the purpose of facilitating a rapid surface for draining. The side drains are placed for this purpose parallel to the axis of the road and connected with the surface in a suitable slope.

Where from the character of the soil good summer roads cannot be had, it would be necessary to make wooden turnouts from space to space, to prevent the inconvenience and delay of miry roads. This can be effected by laying at these points a wooden track of double width, to enable vehicles meeting to pass each other. It is recommended to lay these turnouts on four or five sills, to spring

the boards slightly at the centre, and spike their ends to the exterior sills.

In some of the earlier plank roads a width of 16 feet was given to the wooden track, the boards of which were laid upon four or five rows of sills. But experience soon demonstrated that this was not an economical plan, as it was found that vehicles kept the centre of the wooden surface, which was soon worn into a beaten track, whilst the remainder was only slightly impaired. This led to the abandonment of the wide track for the one now usually employed, which answers all the purposes of the traffic and is much more economical, both in the first outlay and for subsequent renewals and repairs. Plank roads possess great advantages in a densely-wooded country, and will be found superior to every other kind as a temporary expedient.

446. The cost per mile ranges from $1000 to $4000, and the life is about eight years.

447. Log Roads.—When a road passes over soft swampy ground, always kept moist by springs which cannot be drained without too much expense, and which is surrounded by a forest, it may be cheaply and rapidly made passable by felling a sufficient number of young trees, as straight and as uniform as possible, and laying them side by side across the road at right angles to its length. This arrangement is well known under the term "corduroy road." Though its successive hills and hollows offer great resistance to draught and are very unpleasant to persons riding over it, it is nevertheless a very valuable substitute for a swamp, which in its natural state would at times be utterly impassable.

448. Charcoal.—In some of the Western States, where wood is abundant and cheap, roads covered with charcoal have been made as follows: Logs from six inches to two feet in diameter and from twelve to twenty-four feet long are cut and piled lengthwise along the road about six feet high, being nine feet on the bottom and two on top, and then covered with straw and earth, or simply with sods, and burned in the manner of coal-pits. The covering is taken from the sides of the road, and the ditches thus formed afford good drainage. After the timber is converted into charcoal, the earth is removed to the side of the ditches, the coal raked down to a width of fifteen feet, leaving it two feet thick at the center and one at the sides, and the road is completed.

449. A road thus made in Michigan cost $660 per mile, and is said to be very compact and free from mud or dust. At a season when the mud on the adjoining earth road was half-axletree deep, on the coal road there was not the least standing, and the impress of the feet of a horse passing rapidly over it was like that made on hard-washed sand, as the surf recedes, on the shore of the lake. The water was not drained from the ditches, and yet there were no ruts or inequalities in the surface of the coal road, except what was produced by more compact packing on the line of travel. It is probable that coal will fully compensate for the deficiency of limestone and gravel in many sections of the West, and, where a road is to be constructed through forest land, that coal may be used at a fourth the expense of limestone.

450. **Iron.**—Iron is eminently durable, but as a pavement it is a failure. It is so slippery even when roughened that horses cannot gain a foothold on it. About thirty years ago Cortlandt Street in New York was paved with it. In order to guard against slipperiness the surface was made rough and consisted of hexagonal projections about an inch in size, separated by depressions of about the same size. It was both rough and noisy; the horses caught their calks in the depressions and twisted off their shoes, and in spite of its roughness the horses fell frequently and with disastrous results in tearing their knees on the sharp projections. It remained in use but a short time and was replaced with stone. Combinations of wood and iron, concrete and iron, are frequently introduced and experimented with, but so far none have been a practical success.

450a. **Furnace Slag.**—Slag and cinders from iron and copper works may be employed with advantage when they are procurable, and when no stone sufficiently tough to withstand the action of heavy traffic can be obtained. They are both very durable, but care is required in the selection of the tougher sorts. They have no binding properties, and on this account are sometimes used with limestone; a rough surface will, however, always result from the unequal wear of two materials so different in hardness. Limestone scrapings, coal ashes or clay, laid on as a binding material, aid consolidation very much, and also prevent injury to horses' feet from the sharp edges of the fresh-laid slag.

CHAPTER IX.

FOUNDATIONS.

451. THE stability, permanence, and maintenance of any pavement depends upon its foundation. If the foundation is weak, the surface will quickly settle unequally, forming depressions and ruts. With a good foundation the condition of the surface will depend upon the material employed for the pavement and the manner of laying it.

452. The essentials necessary to the forming of a good foundation are:

(1) The entire removal of all vegetable, perishable, and yielding matter. It is of no use to lay good material on a bad substratum.

(2) The drainage of the subsoil wherever necessary. A permanent foundation can only be secured by keeping it dry; for, where water is allowed to pass into and through it, its weak spots will be quickly discovered and settlement will take place.

(3) The thorough compacting of the natural soil by rolling with a roller of proper weight and shape until it forms a uniform and unyielding surface.

(4) The placing on the natural soil so compacted a sufficient thickness of an impervious and incompressible material which will effectually cut off all communication between the soil and the bottom of the pavement.

453. The character of the natural soil over which the roadway is to be built has an important bearing upon the manner of forming and the kind of foundation; each class of soil will require different treatment. Whatever its character, it must be brought to a dry and tolerably hard condition by draining and rolling. Sands and gravels which do not hold water present no difficulty in securing a solid and secure foundation; clays and soils retentive of water are the most difficult. Clay should be excavated to a depth of at least 18 inches below the surface of the finished covering, and the space

so excavated filled in with sand, furnace-slag, ashes, coal-dust, oyster-shells, broken brick, or other materials which are not excessively absorbent of water. Whichever of these materials is used, it should be thoroughly consolidated before laying the pavement.

In ground saturated with water a foundation may be formed of logs or layers of fascines; but unless the nature of the ground is such as will always insure the timber being kept in a wet or damp state, it will soon rot and the road will go to pieces. Therefore they should never be employed unless under unavoidable circumstances.

454. Sand.—Sand and planks, gravel, and broken stone have been successively used to form the foundation for pavements; but although eminently useful materials, their use for this purpose has been and always must prove a failure. They are inherently weak and possess no cohesion, and the main reliance both for strength and wear must be placed upon the surface-covering. This covering, being usually (except in case of sheet asphalt) composed of small units with joints between them varying from one half to one and a half inches possesses no elements of cohesion, and under the blows and vibrations of traffic the independent units or blocks will settle and be jarred loose. They are porous and the subsoil quickly becomes saturated with urine and surface-waters percolating through the joints; winter frosts upheave them and the surface of the street becomes blistered and broken up in dozens of places. The defects of plank foundations are stated in Art. 186.

Although sand, gravel, etc., by themselves are unsuitable as foundation materials for block pavements, still when used with judgment they form excellent foundations for broken-stone roads.

455. Sand Foundation.—The natural soil having been trimmed and thoroughly compacted by rolling to the cross-section which is to be given to the covering, a layer of sand four inches thick is spread uniformly, thoroughly wetted by sprinkling, and rolled; two other layers of four inches each are in like manner added and rolled. The compression effected by a roller weighing ten tons will reduce the thickness of twelve inches to eight a greater final thickness than this is unnecessary unless the natural soil is very yielding, when it may be increased to twelve or sixteen inches.

456. Blast-furnace Slag.—The ordinary brittle slag makes a very good foundation for a road, particularly on clay or wet soils, as by rolling the top pieces form a powder that fills the interstices

between the lower fragments so thoroughly that neither clay nor mud can work up through the layer, and on this the more durable wearing materials can be placed. It was found impossible to form any roads on the soft clay surface of the Centennial Fair grounds at Philadelphia until their beds had been prepared by a layer of well-rolled furnace-slag, after which they stood heavy teaming without under-drainage; the binding of the fragments of slag with the thorough filling of the interstices preventing any mud from working up through the first or cover layer, thus keeping the road from breaking up.

457. Concrete.—As a foundation for all classes of pavement (broken stone excepted) hydraulic-cement concrete is superior to any other. When properly constituted and laid it becomes a solid coherent mass capable of bearing great weight without crushing, and which if it fail at all must fail altogether. It is the most costly, but this is balanced by its permanence and saving in the cost of repairs to the pavement which it supports. It admits of access to subterraneous pipes with less injury to the neighboring pavement than any other, for the concrete may be broken through at any point without unsettling the foundation for a considerable distance around it, as is the case with sand or other incoherent material; and when the concrete is replaced and set, the covering may be reset at its proper level without the uncertain allowance for settlement which is necessary in other cases.

458. Thickness of Concrete.—The thickness of the concrete bed must be proportioned by the engineer; it should be sufficient to provide against breaking under transverse strain caused by the settlement of the subsoil. On a well-drained soil six inches will be found sufficient, but in moist and clayey soils twelve inches will not be excessive. On such soils a layer of sand or gravel, spread and compacted before placing the concrete, will be found very beneficial.

459. Concrete (called *beton* by the French engineers) is a species of artificial stone composed of (1) the matrix, which may be either lime or cement mortar, usually the latter, and (2) the aggregate, which may be any hard material, as gravel, shingle, broken stone, shells, brick, slag, etc.

The essential quality of concrete seems to be that the material of the aggregate should be of small dimensions, so that the cement-

ing medium may act in every direction round them, and that the latter should on no account be more in quantity than is necessary for that purpose. The aggregate should be of different sizes, so that the smaller shall fit into the voids between the larger. This requires less mortar and with good aggregate gives a stronger concrete. Broken stone is the most common aggregate.

It is usual to require that the stone shall be broken so as to pass any way through a 2-inch ring. To insure compact packing the aggregate should consist of a mixture of broken stone ranging from 1 to 3 inches, and pebbles which are at least equal to the strength of the mortar. Sun-dried or rain-soaked material is to be strictly avoided. The choice of the cementing substance, lime or cement, depends upon the use of the concrete.

460. The strength of concrete depends upon the cohesion of the matrix, adhesion to the aggregates, irregular bonding or interlocking of the coarser fragments, and upon the strength and proportion of each ingredient.

Concrete for pavement foundations should be dense and homogeneous, with the voids of the aggregate thoroughly filled with mortar, and the latter must again be so constituted that the voids between the grains of sand shall be closely filled by the cement paste.

Good concrete has a specific gravity of 1.5 to 2.5, according to its composition of crushed bricks or heaviest stones. A cubic yard weighs from 2500 to 3900 pounds.

461. Proportions.—The proportions of the ingredients required for the manufacture of concrete may be ascertained by measuring the respective voids.

The proportion of voids may be determined by experiment in either of the ways described in Art. 373, page 176.

The voids of broken stone, in which the size and shape of the pieces are nearly uniform, are about 0.5 of the mass. If the pieces are not uniform, the voids are about 0.4 of the mass. The voids in gravel vary, but average about 0.5 of the mass.

462. The voids between the grains of sand will probably average 33 per cent; that is to say, 67 per cent of the cubic contents to be occupied by the mortars are absorbed by the solids of the grains of sand and 33 per cent are to be filled in with cement, so that a mortar of one part of cement to two of sand, and no more, is

required for water-tight work. A strong water-tight concrete will contain by volumes as follows: cement, sand, stone, as 1 : 2 : 5; and with fine Portland this mixture may reach after four weeks a compressive strength of 175 tons per square foot. The eight volumes of material fill finally a space of about 5.2 volumes.

463. The addition of water must be limited to the actual requirements, which fluctuate for natural cements between 50 and 55 per cent, and for Portland cement between 40 and 45 per cent, of the weight of the cement used. Plasticity is only to be attained by diligently tamping an apparently dry mass until water appears on the surface.

464. The following are some of the more usual proportions: Concrete

American hydraulic cement	1 part
Sand	2 parts
Broken stone	3 "

Portland cement	1 part
Sand	3 parts
Broken stone	5 to 7 "

Portland cement	1 part
Sand	$2\frac{1}{2}$ parts
Gravel	3 "
Broken stone	5 "

Tests of this formula showed a filling of voids within 6% of the whole volume. One barrel of cement weighing 380 pounds net made 1.18 cubic yards of concrete weighing when dry 136 pounds per cubic foot. Cost per cubic yard, $6.

For one cubic yard of concrete of stone, gravel and sand, without voids, the following quantities of materials are required:

Broken stone 50% of its bulk voids	1.00 cubic yard
Gravel to fill voids in the stone	.50 " "
Sand " " " gravel	.25 " "
Cement " " " sand	.125 " "

For one cubic yard of concrete of stone and sand without voids, the following quantities of materials are required:

Broken stone 50% of its bulk voids	1.00 cubic yard
Sand to fill voids in the stone	.50 " "
Cement " " " sand	.25 " "

465. Mixing.—The concrete may be mixed by hand or by machinery. In the first method the cement and sand are mixed dry. About half the sand to be used in a batch of concrete is spread evenly over the mortar board, then the dry cement spread evenly over the sand, and then the remainder of the sand is spread on top of the cement. The sand and cement are then mixed with a hoe or by turning and re-turning with a shovel. It is very important that the sand and cement be thoroughly mixed. A basin is then formed by drawing the sand and cement to the outer edges of the box, and the water is poured into it. The sand and cement are then thrown back upon the water, the whole mass thoroughly mixed with the hoe or shovel, and then levelled off. The broken stone should be sprinkled with sufficient water to remove all dust and thoroughly wet the entire surface. The amount of water required will vary considerably with the absorptive power of the stone and the temperature of the air. The wet stone is then to be spread evenly over the top of the mortar, and the whole mass thoroughly mixed by turning up with a shovel. When the aggregate consists of broken bricks or other porous material it should be thoroughly wetted and time allowed for absorption previous to use; otherwise it will take away part of the water necessary to effect the setting of the cement.

466. Laying.—After mixing, the concrete is conveyed in wheelbarrows and compacted in position by ramming in layers. When the thickness is to be 6 inches it should be laid in one layer; if thicker, in two equal layers, the surface of the first layer being moistened before spreading the second. If too much water has been used in mixing, it will be impossible to compact it by ramming. When ready for use the concrete should be quite coherent and capable of standing at a steep slope without the water running from it. Ramming, when properly done, consolidates the mass about 5 or 6 per cent, rendering it less porous, and very materially stronger. The rammers are, like those used in street-paving, of wood, about 4 feet long, 6 to 8 inches in diameter at foot, with a lifting-handle, and shod with iron; weight about 35 pounds. They are let fall six or eight inches. The men using them, if standing on the concrete, should wear india-rubber boots to protect their feet from corrosion by the cement.

The ramming should be continued only until the water begins

to ooze out on the upper surface. Too severe or long-continued pounding injures the strength of the concrete by forcing the broken stone to the bottom of the layer, and by disturbing the incipient set of the cement. When the concrete is rammed, walking should not be permitted on it for at least 12 hours; 24 would be better. It is necessary to give the concrete abundance of time to dry and set. This precaution is indispensable. If an undue amount of moisture should remain after the superstructure is laid, it will destroy the homogeneous qualities of the concrete.

467. A correctly proportioned concrete has fully as much strength as the cement-mortar used in mixing it. By diminishing the aggregate below the calculated quantity the cost of concrete is increased without benefit to strength.

The transverse strength of concrete ranges between 50 and 400 pounds, depending upon the character of the cement and skilfulness of manipulation.

468. Compressive Strength.—Trautwine says that cubes of Portland cement, sand, and broken stone, "well made and rammed, should, either in air or in water, require to crush them at different ages not less than about as follows:

Age in months	1	3	6	9	12
Tons per square foot	15	40	65	85	100

Under favorable conditions of materials, workmanship, and weather, the strengths may be from 50 to 100 per cent greater."

The compressive strength of 6-inch cubes of concrete exposed to the air for six months, as determined in connection with the construction of the St. Louis Bridge, was as follows: with the proportions of 1 part cement (Akron and Louisville), 1 part sand, and 4 parts broken limestone, the mean compressive resistance for nine trials was 1200 pounds per square inch (85 tons per square foot); and with the proportions of 1, 2, 4, respectively, the average resistance for twelve trials was 940 pounds per square inch (70 tons per square foot).

Tests with the United States testing-machine at Watertown, Mass., between steel gave an average of 1544 pounds per square inch (110 tons per square foot) for 4-inch to 6-inch cubes of concrete 46 months old composed of 1 part Rosendale cement-paste, 1½ parts sand, and 6 parts broken stone. Under the same condi-

tions, concrete composed of 1 part Rosendale cement-paste, 3 parts sand, and 6 parts broken stone stood 1021 pounds per square inch (73 tons per square foot). Another sample of cement gave 1078 pounds per square inch (77 tons per square foot) for concrete 22 months old composed of 1 part cement paste, 3 parts sand, and 4 parts broken stone. Ten experiments with a single sample of Portland cement gave 3067 pounds per square inch (219 per square foot) for concrete composed of 1 part cement paste, 3 parts sand, and 6 parts broken stone. The concrete under the Washington monument, composed of 1 part Portland, 2 parts sand, 3 parts pebbles, and 4 parts broken stone, when six months old stood 2000 pounds per square inch (144 tons per square foot).

Experiments made in connection with the construction of the Vyrnwy dam—built to impound water for the supply of Liverpool, England—gave an average strength from six experiments, for cubes of mortar composed of 1 part Portland cement and 2 parts of sand from 32 to 37 months old, crushed between pine cushions ¼ inch thick, of 4428 pounds per square inch (284.7 tons per square foot); and cubes of concrete composed of gravel and sufficient mortar composed as above to fill the interstices gave an average strength, for two cubes 35 and 36 months old, of 3497 pounds per square inch (224.9 tons per square foot). The blocks were made from the concrete actually used in the work, and were moulded by ordinary workmen without supervision, with the intention of securing blocks representative of the concrete as laid in the work. For cubes of the concrete tested between "mill-boards" (straw-boards) the same series of experiments gave results as follows:

Age of the Blocks. Months.	Number of Experiments.	Mean Crushing Strength.	
		Lbs. per sq. in.	Tons per sq. ft.
32–36	3	2,365	170.4
20–30	6	2,278	164.0
5–8	2	1,742	125.5
1–2½	7	1,477	106.4

469. Cost.—The cost of concrete varies greatly, depending upon the kind of mortar, whether lime or cement; upon the richness

of the mortar; upon the proportion of aggregate to mortar, upon the cost of the ingredients and of the labor, etc.

It varies from $4.00 to $6.00 per cubic yard with Rosendale cement, and from $6.00 to $9.00 per cubic yard with the Portland cement. The cost for pavement foundations ranges from 94 cents to $1.50 per square yard.

PORTLAND-CEMENT CONCRETE.

Proportions:

Cement	1 part
Sand	3 parts
Broken stone	5 "

Portland cement	1.28 bbls.	at $2.60	=	$3.33
Sand	0.50 cu. yd.	" 1.30	=	0.65
Broken stone	0.90 "	" 1.23	=	1.12
Labor	0.91 day	" 1.75	=	1.59
Foreman	0.07 "	" 3 00	=	0.21
Total cost of one cubic yard in place				$6.90

470. An excellent concrete is made of 80 parts of furnace-slag (crushed) and 20 parts of asphaltic cement; the slag and cement should be heated before mixing, and be laid while hot.

471. As the value of concrete depends principally upon the matrix or cementing medium, a thorough knowledge of the mortar and the characteristics of its ingredients is indispensable for successful manipulation.

The material employed for the manufacture of mortar are:

(1) Lime (common and hydraulic).

(2) Hydraulic cements (natural and artificial).

(3) Sand.

472. Common Lime is derived from the calcination of pure and impure limestones, and is extensively employed for the manufacture of mortar used in building construction. It is unsuitable for the manufacture of concrete. Concretes in which it is used as a matrix are permeable, weak, and liable to rupture from sudden shock. Lime mortar sets or hardens slowly, and if deprived of air setting may never take place, as it hardens mainly through the aid of carbonic acid gas, which it absorbs slowly from the atmosphere.

Hydraulic Lime is in many respects similar to common lime, but possesses the property of hardening under water. This class of

lime is much used in Europe, but there is none produced in the United States.

473. Hydraulic Cement is of two classes, natural and artificial. The American natural or Rosendale type of cement is made by burning in ordinary draw-kilns cement rock composed of limestone intimately mixed with silica, alumina, magnesia, etc., and grinding the calcined product to powder. The cement thus produced depends for its uniformity upon the homogeneity of the rock from which it is made.

These cements are of a porous, globular texture, with a specific gravity of about 2.7. They do not heat up nor swell sensibly whilst they are mixed; they set quickly in air, but harden slowly under water, without shrinking, and attain great strength with well-developed adhesive force.

Color.—The color of these cements gives no clue to their cementitious value, since it is chiefly due to oxides of iron and manganese, which bear no direct relation to the hydraulic properties.

To insure efficient chemical action in hardening, the grinding must be carried to the production of impalpable powder. These cements bear admixture of sand to double their own volume and over. For mixing pure cements from 30 to 40 per cent of water must be added.

Many American cements of this class contain large percentages of carbonate of magnesia. Pure carbonate of magnesia, when burned at a moderate heat, ground to fine powder, and made into paste with sea-water, makes a cement which is superior in hardness and strength to any other, not excepting even Portland cement. These cements give good adhesion to stones and bricks, because they part with their surplus water more slowly than the others. Whenever judiciously selected and conscientiously manipulated they have given full satisfaction. Many causes co-operate in affecting rocks of the compound character required for the production of hydraulic cements. Deleterious material is disseminated through the various strata of a quarry in constantly and widely changing proportions, each stratum exhibits heterogeneous features. Hence it taxes judgment, begotten of large experience, honesty, carefulness, and skill, to keep up reasonably uniform quality.

Different quarries show dissimilar stones. The best brands vary greatly in chemical composition. Fineness, density, thorough and

homogeneous mixture, humidity, accessory ingredients, enter largely into the problems.

To preserve the activity and strength of the natural cements, air and moisture must be excluded by careful packing and dry storage of the barrels; otherwise the premature development of carbonate of lime will interfere with the subsequent hydration.

Prof. DeSmedt found for our native Virginia cements in pure state, after 30 days' exposure, 170 to 250 pounds tensile strength per square inch, which increased in 11 months to 316 to 381 pounds. Mixed with equal proportions of sand he obtained from 116 to 155 pounds and 180 to 190 pounds as above.

Gillmore states the adhesion of Rosendale cement to front bricks, after 28 days, when pure to be 30 pounds, and when mixed with one or two parts of sand 16 and 12 pounds.

Clarke reports the tensile strength of these Rosendale cements, pure, after one and twelve months, as 145 and 290 pounds respectively; when mixed 1 to 1, to 116 and 256 pounds; when mixed 1 to 2, 60 and 180 pounds; and when mixed 1 to 3, 35 and 121 pounds after the same periods.

One cubic foot of Rosendale cement weighs 49 to 59 pounds. The proportion of tensile to compressive strength averages probably after a month 1 to 4, and rises after two years about 1 to 6 or 7.

The specifications of the Engineers' Department of the District of Columbia require seven days after mixture, for neat, natural cement, 95 pounds, and for mixtures with one and two parts of sand 56 and 22 pounds tensile strength per square inch, respectively. The gradual increase of strength by time is carefully noted and establishes the reputation of the accepted brands.

474. Natural Portland Cement.—Portland cement derives its name from the resemblance which hardened mortar made of it bears to a stone found in the isle of Portland, off the south coast of England. It is manufactured in those rare cases where rocks are traced which contain combinations of lime and silica of alumina in the chemical proportions and physical condition found necessary for producing artificial Portland.

The treatment then differs from that of ordinary cement only in the higher temperature for burning. There are extensive works of this class around Perlmoos in Germany, Grenoble in France, etc.

475. Artificial Portland Cement.—Fully 95 per cent of all the

Portland cement used at the present day is artificial. It is made by thoroughly mixing together, in suitable proportions, clay and finely pulverized carbonate of lime (either chalk, marl, or compact limestone), burning the mixture in kilns at a high temperature, and then grinding the burned product between ordinary millstones. The result is an impalpable, dense, drossy, steel-hard powder, having a specific gravity of 3.0 to 3.15. A few weeks' storage seasons the powder and makes it ready for use.

As accessory ingredients, sulphate of lime and other combinations of sulphur occur in Portland cement, which, combining with seven chemical equivalents of water, and even more, cause considerable increase of volume. This explains why a large percentage of sulphuric acid endangers the durability of hydraulic cements, while a small addition of it tends to increase their strength.

If the contents of clay in Portland cement rise above 50 per centum of the calcined lime (overclayed cement), complete vitrification is to be feared during the burning; the lack of cementing substance (lime) is felt, and the cement becomes an inert mass unfit for use. On the other hand, an "overlimed" cement tends toward quick setting and blowing or expansion. These effects, due to the presence of free caustic lime, may be remedied by airing such cement for a day or more, when the caustic lime will absorb carbonic acid from the air and become a neutral body for the cement. There is for each material one most favorable proportion in which the tendencies to shrinking and to expanding neutralize each other, so that a good cement is the result.

The chemical reactions require for cement burned at white heat only half as much water as those burned at moderate heat; this no doubt contributes to the superior strength of the Portland. Water in the proportion of 20 to 25 per cent of the weight of the cement generally suffices for mixing pure cement. Mixtures with sand, according to its dry or moist state, require increased quantities. By far the strongest mortar, with or without sand, results from mixtures in a state of incoherent dampness, with no more plasticity than absolutely necessary for the work in hand.

Too long-continued stirring or excess of water prevents setting, a paste being formed which slowly hardens by shrinkage, caused by evaporation and pressure, analogous to fat lime.

Normal material and treatment result in slow and cool setting

but comparatively low adhesive power. The tensile strength increases for a slow-setting Portland cement gradually for about two years, while the compressive strength increases for many years.

All Portland cements bear the admixture of large quantities of sand, but an excess retards setting and reduces the tensile strength. Mixtures of 1, 2, 3, and 4 parts of sand to one part of cement showed one year after mixing a reduction of 25, 50, 60, and 70 per centum (Michaelis and Grant's tests). An excess of sand makes a harsh, raw mixture, difficult of manipulation and hence unsuitable for architectural work.

Magnesia as a prominent ingredient of the limestone, used as raw material for producing Portland cement, acts badly, even treacherously. It does not harden hydraulically either with silica or with alumina; hence it remains as calcined magnesia, simply ballast, which lessens the quantity of hydraulic substances. Mixed with water it forms a hydrate of no high cementitious value. The absorption of water proceeds the slower the stronger the magnesia has been calcined. In consequence the hydration takes place at a time when the hydraulic hardening of Portland cement is virtually completed, and the swelling, due to larger masses of magnesia, causes a destruction of this cohesion already attained, and this has caused the collapse of bridges and buildings, and the crumbling of plastering on walls in France, according to the observations of Lechartier, Deville, and Calvert. This belated increase of volume escapes observation under the ordinary tests for expansion and requires special caution. Portland cements containing more than 5 per cent of magnesia should be rejected.

476. Characteristics of Portland Cement.

Color.—The color should be a dull greenish gray, caused by the dark ferruginous lime and the intensely green maganese salts. Any variation from this color indicates the presence of some impurity: blue indicates an excess of lime; dark green, a large percentage of iron; brown, an excess of clay; a yellowish shade indicates an underburned material.

Fineness.—It should have a clear, almost floury feel in the hand; a coarse, gritty feel denotes coarse grinding. The fineness should be such that 80 per cent will pass through a sieve of 2500 meshes to the square inch.

Weight.—It should weigh from 84 to 88 pounds per cubic foot.

A cement weighing from 70 to 80 pounds per cubic foot is invariably a weak one, though it may be of the requisite fineness; at the same time a heavy cement if coarsely ground is also weak and will have no carrying capacity for sand.

Light weight may be caused by laudable fine grinding, or by objectionable underburning. In testing, weight and fineness must be taken in conjunction.

Specific Gravity, between 3 and 3.05. As a rule the strength of Portland cement increases with its specific gravity.

Tensile Strength.—When moulded into a briquette and placed in water for seven days it should be capable of resisting a tensile strain of from 300 to 400 pounds per square inch.

Setting.—A pat made with the minimum amount of water should set in not less than three hours nor take more than six hours.

Expansion and Contraction.—Pats left in the air or placed in water should during or after setting show neither expansion nor contraction, either by the appearance of cracks or change of form.

A cement that possesses the foregoing properties may be considered a fair sample of Portland cement and would be suitable for any class of work.

Portland cement, although the best material that can be used as a cementing medium, should not be used by any one who is not prepared to take the trouble and incur the trifling expense of testing it; because if manufactured with improper proportions of its constituents, or improperly burnt, it may do more mischief than the poorest lime.

477. Cement Tests.—As the value of cements varies greatly with their physical properties, and since one lot of cement is liable to differ very much from another lot of the same brand, it is necessary, in order to obtain an idea of their relative merits, to make a series of tests as to the effect that the amount of sand, water, temperature, pressure, age, etc., has upon them.

How to carry out and interpret the results of various tests of cements involves great care and study and erroneous conclusions may be arrived at when undertaken by those not thoroughly acquainted with the subject and with the particular cements to be tested.

478. The properties of a cement which are usually examined to determine its constructive value are (1) color, (2) weight, (3) activity, (4) soundness, (5) fineness, and (6) strength. The last three are the most important.

479. Color.—As previously stated, the color of American natural cements has no influence upon its quality. The color of these cements is generally brown, ranging from very light to dark brown. Sometimes a very light color indicates an inferior or underburned rock. With Portland cement it is different; the color has an important bearing upon its quality; it should be dull greenish gray, and any deviation from this indicates impurities, as stated in Art. 476.

480. Weight.—For any particular cement the weight varies with the degree of heat in burning, the degree of fineness in grinding, and the density of packing. Other things being the same, the harder-burned varieties are the heavier. The finer a cement is ground the more bulky it becomes, and consequently the less it weighs.

The weight per unit of volume is usually determined by sifting the cement into a measure as lightly as possible, and *striking* the top level with a straight-edge. In careful work the height of fall is specified. Since the cement absorbs moisture, the sample must be taken from the interior of the package. The weight per cubic foot is neither exactly constant, nor can it be determined precisely; and for the practical purpose of the user is of very little service in determining the value of a cement. However, it is often specified as one of the requirements to be fulfilled.

481. The following values, determined by sifting the cement with a fall of three feet into a box having a capacity of one tenth of a cubic foot, may be taken as fair average for ordinary cements. The difference in weight for any particular kind is mainly due to a difference in fineness.

Portland, English and German	77 to 90 lbs. per cu. ft.
" fine ground French	69 " " "
" American	95 " " "
Roman	54 " " "
Rosendale	49 to 56 " " "
Lime of Teil	50 " " "

Since a bushel is 1.244 cubic feet, the weight per bushel can be approximately obtained by adding 25 per cent to the above quantities. However, it is better to make the cubic foot the standard unit measure.

482. Activity.—A mortar is said to have set when it has attained such a degree of induration that its form cannot be altered without causing a fracture, i.e., when it has entirely lost its plasticity. Some cements set quickly, while others are comparatively slow in developing the first indications of hydraulicity. This property is called hydraulic quickness or activity. A quick-setting cement is especially valuable in constructions under water.

A distinction should be carefully made between hydraulic activity and hydraulic energy or strength. The former refers to the time required to attain a small degree of strength, and the latter to the amount of strength ultimately attained. There is no necessary relation between time of setting and ultimate strength; but, as a general rule, the slow-setting cements ultimately attain to a greater strength than quick-setting ones.

The activity of cement may be increased by adding a quicker-setting cement, as plaster of paris, lime, clay, or even grease,—all such ingredients, particularly the last, weakening the resulting mortar.

483. "The effects of a variation of temperature upon the hydraulic quickness of mortars—whether derived from hydraulic cement, a mixture of common lime and pozzuolana, or produced by artificial means—is very marked: so much so, indeed, that in all comparative tests of this kind it is important to adopt some fixed standard of temperature, not only for the water with which the cement is mixed, as well as that in which the cement is immersed, but for the dry ingredients and the surrounding atmosphere. All cements are not equally sensitive to a variation of temperature."

The rise in temperature is much more apparent in the setting of quick-setting cements than in others, because the external cooling is relatively much less.

Herzog obtained the following results concerning the rise in temperature of a Portland cement, which he formed while wet into a prism 10 centimeters long and at another time into a prism 20 centimeters long. In each case the original temperature was 13.5 degrees C.

TEN CENTIMETERS LONG.

Immediately after moulding	16	degrees C.
After 30 minutes	17	" "
" 70 "	17.5	" "
" 4 hours	18	" "
" 5 "	18.5	" "
" 6 "	23.5	" "
" 7 hours and 30 minutes	27	" "
" 8 " max	29.5	" "

TWENTY CENTIMETERS LONG.

Immediately after moulding	19	degrees C.
After 1 hour and 30 minutes	20.5	" "
" 2 " " 30 "	22	" "
" 4 " " 30 "	24	" "
" 5 " " 30 "	38	" "
" 7 "	43	" "
" 8 "	45	" "
" 8 " and 30 minutes, max	45.5	" "

Thus we see that the temperature increased 16 degrees in one case and 32 degrees in the other; accordingly the rise in temperature was proportional to the side of the cement-prism. Thus it will be seen that all theories about the rise in temperature of setting cements have no value unless they take the volume of cement into account.

484. The quantity of water used in gauging the cement has great influence upon the tensile strength and must be regulated according to the kind of cement, since every cement has a certain given capacity for water; of course, however, in practice a quantity that is somewhat greater than this must generally be used.

In the following table by Feichtinger it will be seen that the amount of water absorbed from the air by Portland cements (column 1) and hydraulic limes (columns 2, 3, 4) varies considerably with the time.

In practice about 50 per cent of water is generally used, which is a great excess, so that there is usually about 30 per cent of water to be driven off by evaporation. If an undue amount be employed, the tensile strength is reduced to a considerable extent. On the other hand, if the quantity be as small as possible consistent with proper manipulation, the result will be much higher. From numerous

TABLE XLIV.

AMOUNT OF WATER ABSORBED BY CEMENT AND LIME.

	1 per cent.	2 per cent.	3 per cent.	4 per cent.
Fresh ground........	.99	1.28	.61	6.79
After 4 hours........	1.41	1.67	.71	7.80
" 20 "	2.29	2.08	1.14	8.26
" 3 days	5.62	3.42	1.82	8.07
" 7 "	6.58	3.85	2.15	11.20
" 14 "	7.96	4.46	2.63	11.80
" 28 "	10.52	8.30	6.20	14.48
" 80 "	11.56	9.50	7.40	14.65

experiments it has been found that, as a general rule, a proportion of 1 part of water to 3 parts of cement by measure, or 1 to 3½ by weight, is the best, both as regards convenience of mixing and results. With a much less quantity the gauging would be so stiff as to render the manipulation most difficult; the risk of air-holes, the reduction of which to a minimum is a point to be particularly attended to, would be augmented; the angles of the mould would be imperfectly filled, and generally a very imperfect briquette formed. Consequently the results of such tests would be unsatisfactory and unreliable. In general practice it will be found that a slight variation in the above-mentioned proportions will be necessary, depending upon the age and degree of fineness of the cement, but only to a limited extent.

485. Effect of Age on the Cement.—The age of Portland cement, although strictly not a condition of manufacture, is an important element in its economical and safe use. Cement not only improves generally by keeping, but the older the cement the less danger will there be of its blowing, as the free lime would be acted upon by the atmosphere, causing it to slake and reducing the danger and expansion to a minimum. The age has also been found to exert considerable influence upon the rate of setting, causing it to require a much longer time to set than new cement.

486. Tests of Activity.—To test hydraulic activity, mix cement with 25 to 30 per cent of its weight of clean water having a temperature of between 65 and 70 degrees Fahr., to a stiff plastic mortar, and make one or two cakes or pats two or three inches in diameter and about ½ inch thick. As soon as the cakes are pre-

pared immerse in water at 65 degrees Fahr., and note the time required for them to set hard enough to bear respectively a $\frac{1}{12}$-inch wire loaded to weigh $\frac{1}{4}$ of a pound and a $\frac{1}{24}$-inch wire loaded to weigh 1 pound. When the cement bears the light weight, it is said to have begun to set; when it bears the heavy weight, it is said to have entirely set. Cements, however, will increase in hardness long after they can just bear the heavy wire. The activity of the cement is measured by the interval which elapses between the time when the first weight is supported and that when the second is just borne. Notice that with the wires as above the weight per unit of surface in the second case is 16 times as much as in the first. Hence it is not necessary to have the diameters as stated, but only to have the pressure per unit of area 16 times greater in the one case than in the other. The same wire may be used in both tests, the load only being varied. Different kinds and brands of cement vary greatly in the time required to set. Some brands of Rosendale cement will support the heavy wire in two minutes, and some brands of Portland in not less than 12 hours. Cold retards the setting. Freshly-ground cements set quicker than old ones. The quick-setting cements usually set so that experimental samples can be handled within five to thirty minutes after mixing. The slow-setting cements require from 1 to 8 hours.

487. Quick- and Slow-setting Cements.—Cements which set in less than half an hour are termed quick-setting, and those which do not set before two hours, slow-setting. These distinct definitions ought to be specially introduced in important specifications, where they will prevent misunderstandings as to what is meant by a slow-setting cement. Excepting special cases, slow-setting cements are more trustworthy.

488. Soundness.—Soundness refers to the property of not expanding or contracting or cracking or checking in setting. These effects may be due to free lime, free magnesia, or to unknown causes. Testing soundness is therefore determining whether the cement contains any active impurity. An inert adulteration or impurity affects only its economic value, but an active impurity affects also its strength and durability.

The most simple test for detecting expansion in a cement is to make small pats with a trowel, about 3 or 4 inches square, and place them in water when sufficiently set, where they should

remain a few days. If the cement be good, they will show no alteration in form; but any cracks showing on the edges, or other deviations from the original shape of the pats, indicate that the cement is of an expansive nature and therefore not to be trusted. But because a cement will not stand this test it is not in all cases to be condemned as useless, as its expansive or blowing property may be attributable to its being used too soon after leaving the mill. A proper process of cooling, placing it in a thin layer on a dry floor for a short time, will correct the defect.

Contraction due to the cement being over-clayed may be detected by a similar test to that for expansion.

The soundness of a cement may also be tested by placing some mortar in a glass tube (a swelled lamp-chimney is excellent for this purpose) and pouring water on top. If the tube breaks, the cement is unfit for use in damp places. A less delicate and less valuable test than either of the above is to note whether the cement heats when mixed with water. A thermometer is sometimes used in making this test.

The tests of soundness should not only be carefully conducted, but should extend over considerable time. Occasionally cement is found which seems to meet the usual tests for soundness, strength, etc., and yet after a considerable time loses all coherence and falls to pieces.

489. Fineness.—The question of fineness is wholly a matter of economy. Cement, until ground, is a mass of partially vitrified clinker which is not affected by water and which has no setting power. It is only after it is ground that the addition of water induces crystallization. Consequently the coarse particles in a cement have no setting power whatever, and may for practical purposes be considered only as so much sand and essentially an adulterant.

There is another reason why it should be well ground. A mortar or concrete being composed of a certain quantity of inert material bound together by a cementing material, it is evident that to secure a strong mortar or concrete it is essential that each piece of aggregate shall be entirely surrounded by the cementing material, so that no two pieces are in actual contract.

Obviously, then, the finer a cement the greater surface will a given weight cover, and the more economy will there be in its use.

Fine cement can be produced by the manufacturers in three ways: (1) by supplying the millstones with comparatively soft, underburnt rock which is easily reduced to power; (2) by running the stones more slowly, so that the rock remains longer between them; or (3) by bolting through a sieve and returning the unground particles to the stones. The first process produces an inferior quality of cement, while the second and third add to the cost of manufacture.

490. Measuring Fineness.—The degree of fineness of a cement is determined by measuring the per cent which will not pass through sieves of a certain number of meshes per square inch. The committee of the American Society of Civil Engineers recommended the determination "by weight of the per cent that is rejected by sieves of 2500, 5476, and 10,000 meshes to the square inch respectively, the first-mentioned sieve being of No. 35, the second of No. 37, and the third of No. 40, wire gauge. These sieves are usually referred to by the number of meshes per linear inch; the first being known as No. 50, the last as No. 100. It is stated that, as sold, the number of meshes varies somewhat, and the number of wires is generally less by about 10 ten per cent than the number of the sieve. The diameter of the holes is about equal to the diameter of the wire.

German Portland cements are commonly ground finer than English. "Most English manufacturers grind their cement to such a degree of fineness that when sifted through a sieve having 2500 holes (50 by 50) to the square inch, it shall leave a residue of not more than 10 per cent by weight. Cement ground to this fineness will leave from 19 to 20 per cent of residue on a 4900 (70 by 70) sieve, and practically nothing on a 625 (25 by 25) sieve." This is supposed to be the most economical degree of fineness.

Different brands of Rosendale cement vary considerably in their fineness. Those of the best reputation will leave from 4 to 10 per cent residuum on the No. 50 sieve; other brands, from 10 to 23 per cent.

491. Strength.—Although in ordinary practice cements are subject only to compression, yet at the present time all tests are made with a view to ascertaining their tensile strength. The reason for this is that comparatively light strains produce rupture; and that when rupture does take place, the strain causing it is really

due to tension produced by the sinking of one part of the structure and not to compressive force.

492. The Testing-machine.—The details of the form of the specimen to be tested (the briquette), as recommended by the Committee of the American Society of Civil Engineers, are given in Fig. 33. The method of placing the briquette in the machine is shown in Fig. 34. In applying the stress, it is also recommended to make the initial strain 0, and increase it regularly at the rate of 400 pounds per minute until rupture takes place. "For a weak mixture one half the speed is recommended."

There are many machines on the market, made specially for testing the strength of cement. Fig. 35 represents a cement-testing machine which can be made by an ordinary mechanic at an expense of only a few dollars. Although it does not have the conveniences and is not as accurate as the more elaborate machines, it is valuable where the quantity of work will not warrant a more expensive one, and in many cases is amply sufficient.

It was devised by F. W. Bruce for use at Fort Marion, St. Agustine, Florida, and reported to the *Engineering News* by Lieutenant W. M. Black, U. S. A.

The machine consists essentially of a counterpoised wooden lever 10 feet long, working on a horizontal pin between two broad uprights 20 inches from one end. Along the top of the long arm runs a grooved wheel carrying a weight. The distances from the fulcrum in feet and inches are marked on the surface of the lever. The clamp for holding the briquette for tensile tests is suspended from the short arm, 18 inches from the fulcrum. Pressure for shearing and compressive stresses is communicated through a loose upright, set under the long arm at any desired distance (generally 6 or 12 inches) from the fulcrum. The lower clip for tensile strains is fastened to the bed-plate. On this plate the cube to be crushed rests between blocks of wood, and to it is fastened an upright with a square mortise at the proper height for blocks to be sheared. The rail on which the wheel runs is a piece of light T iron fastened on top of the lever. The pin is iron, and the pin-holes are reinforced by iron washers. The clamps are wood, and are fastened by clevis joints to the lever-arm and bed-plate respectively. When great stresses are desired, extra weights are hung on

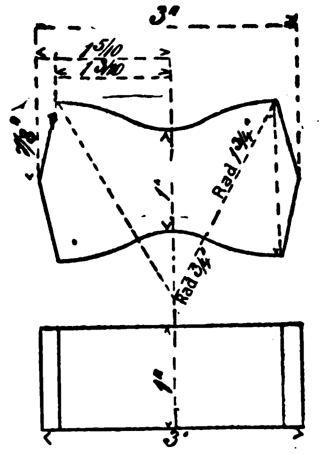


Fig. 33. FORM OF BRIQUETTE.

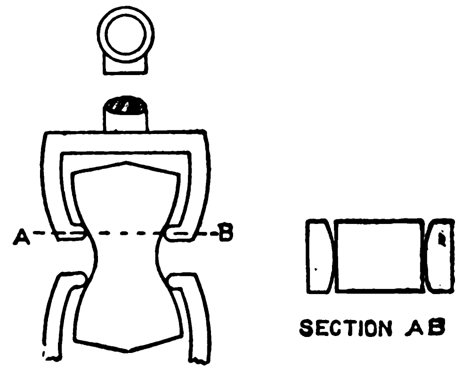


Fig. 34.

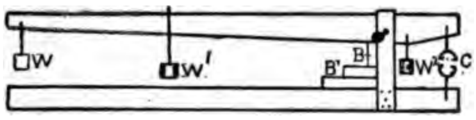


Fig. 35.

the end of the long arm. Pressures of 3000 pounds have been developed with this machine.

493. Most of the tests made in this country and England are carried out for the purpose of ascertaining the strength of neat cements, although such material is rarely, if ever, used without the admixture of sand. In Europe, on the other hand, the practice was established about ten years ago, both by manufacturers and engineers, to determine the value of a cement by testing it when mixed with sand into mortar, the usual proportions of the mixture being three volumes of sand to one volume of cement. It is obvious that the latter practice is preferable, since thereby a knowledge of the strength and properties of the binding material actually used in the work will be gained, and furthermore because no valid inference as to the cohesion of a mortar can be drawn from a statement of the tensile strength of the neat cement.

Tests of this kind should, therefore, be made with cement mortar mixed in the same proportions as contemplated in the work itself, and also with the same sand if practicable, inasmuch as the quality of the latter exerts a marked influence upon the resulting strength of the mortar. In general, it may be said that the greater the proportion of sand in the mortar tested the more accurately can the actual cementing quality of the cement be indicated.

494. Cement-mortar is composed of hydraulic cement and sand in varying proportions, depending upon the kind and quality of the cement. Cement-mortar differs from lime-mortar in its setting, in that it sets within itself without the aid of external elements. Moreover, cement forms by the addition of water a chemical combination throughout all its parts, and setting or hardening takes place throughout the whole mass almost simultaneously. The strength of cement over lime mortar is shown by tests at the Watervliet (N. Y.) Arsenal to be about two to one in favor of the former.

495. Quality of Mortar.—Good mortar should have plasticity when mixed with large quantities of sand, and after solidification compressive strength and tensile strength, as evidence of independent cohesion, power to resist the action of frost and heat, and adhesive qualities for cementing blocks into monolithic bodies. It is to be invariable in volume during and after solidification, to be weather-proof and, for hydraulic works, also water-tight.

496. Quality of Sand.—The sand imparts crushing strength

lessens shrinkage, and saves expense in lime-mortars. Hydraulic cements require sand only at exposed surfaces. Otherwise it serves as an adulterant for reducing a surplus of strength and density to actual requirements of a given bulk. The sand should be clean, sharp, large-grained, not too uniform in size, free from loam, vegetable or clayey substances, well screened, and, if necessary, washed. Admixed particles of clay adhere to the sand and form diaphrams between sand and mortar, which for durable hardening require close contact.

Since sand is mostly used in greater quantities than the cementing substances, it equals them in importance. It is in all classes embedded in the matrix as a mechanical mixture. The tensile and crushing strengths of the same cement, with equal quantities of different qualities of sand, vary more than those of different brands of cement within the same group do among themselves.

497. Quality of Water.—Fresh or salt water may be used in mixing the mortar, provided it is clean; but salt water may, with some natural cements, hinder the setting.

498. Quantity of Water.—In regard to the proper amount of water to be used in tempering a cement-mortar, it may be said that this will depend upon the quality and quantity of sand, as also upon the quality of the cement. From the numerous and careful experiments with Portland and Rosendale cements, made a few years ago by Mr. Eliot C. Clarke, C.E., and published in the Transactions of the American Society of Civil Engineers for April, 1885, the inference was drawn that, "as a rule, American cements require more water than Portland, fine-ground more than coarse, and quick-setting more than slow-setting cements." For experimental purposes in the laboratory, the amount of water added by Mr. Clarke to the dry mixture of sand and cement was usually about one fourth of the weight of the Portland and one third of the weight of the American cement contained in the batch; but these amounts were increased or diminished somewhat in order to obtain mortars of uniform consistency. Mr. Clarke adds, in mixing mortars on the site of public works, and particularly for concrete works, much larger quantities of water than are used by him for testing purposes are commonly added by workmen in order to render the labor of mixing and spreading less difficult, but that the result of this procedure is always a greater or less loss of strength.

For the standard tests of cement-mortars by European engineers the rules prescribe one part by weight of cement, three parts by weight of normal sand, and four tenths of a part by weight of clean fresh water.

499. Strength of Mortar.—Three classes of strength are required in all mortars, viz., adhesive, compressive, and shearing. These strengths are all dependent upon the strength of the cement, the strength of the sand, and upon the adhesion of the former to the latter.

500. Adhesive Strength.—It is commonly assumed that after the lapse of a moderate time the adhesive and cohesive strengths of cement-mortars are about equal, and that in old work the former exceeds the latter. Modern experiments, however, fail to establish the truth of this assumption, and indicate rather that the adhesion of such mortars to bricks or stones is much less than the tensile strength during the first few months; also that the relation between the adhesive and cohesive strengths of both neat cements and mixtures with sand are very obscure. It has been found that the adhesion of mortars to bricks or stone varies greatly among the different kinds of these materials, and particularly with their porosity; it also varies with the quality of the cement, the character, grain, and quantity of sand, the amount of water used in tempering, the amount of moisture in the stone or brick, and the age of mortar. Some cements which exhibit high tensile strength give low values for adhesion, and conversely cements which are apparently poor when tested for cohesion show excellent adhesive qualities. Quick-setting cements are usually found to give greater adhesive strength than slow-setting ones, while in the case of cohesion the opposite is generally true. Under these circumstances, therefore, it is manifest that a test, at various stages of age, of the adhesive properties of a binding material like cement-mortar should be regarded as a very important one, in the case of masonry structures which must soon after completion be subjected to other than compressive strains, and it is to be regretted that so comparatively little information respecting such tests with cements and mortars as made at the present time is available.

To assist somewhat in arriving at a fair measure of the strength of hydraulic mortars at different periods of time, as well as the proper composition of the same, the statistics given in Table XLV have been compiled from a great variety of sources:

TABLE XLV.
Adhesive Strength of Mortars.

Reference-number.	Age in Days when Tested.	Kind of Cement Used.	Materials cemented together.	Average Adhesive Strength in lbs. per sq. in.: Neat Cement	Cement, 1. Sand, 1.	Cement, 1. Sand, 2.	Cement, 1. Sand, 3.	Cement, 1. Sand, 4.	Authority.
1	7	Quick-setting cement	Hard brick	....	....	*23	....	....	Robertson, 1858
2	7	Slow- " "	" "	....	....	*15	....	....	" "
3	7	Portland	Sawed limestone	57	....	....	....	....	I. J. Mann, 1883
4	7	"	Cut granite	41	....	....	....	....	" " "
5	7	"	Polished marble	38	....	....	....	..	" " "
6	7	"	Bridgewater brick	19	....	....	....	....	" " "
7	7	Hydraulic lime	Brick †	24.1	21	18.7	15.3	13.2	Dr. Böhme, 1883
8	7	Portland	" ‡	168	102	38	20	9	Prof. Warren, '87
9	7	"	" §	.	117	53	26	16	" " "
10	16	Quicklime	Limestone	....	....	9–15	....	....	Boistard
11	16	Lime and cement	"	....	..	5	....	....	"
12	28	Hydraulic lime	Brick †	35.1	30.4	25.5	20.9	17.5	Dr. Böhme, 1883
13	28	Portland	" ‡	218	105	45	24	14	Prof. Warren, '87
14	28	"	" §	....	146	73	48	45	" " "
15	20	Quick-setting cement	Hard brick	....	....	*59	....	....	Rober son, 1858
16	30	Slow- " "	" "	....	....	*30	....	....	" "
17	30	Rosendale	Croton brick	30.8	15.7	12.3	6.8	5.2	Gen. Gillmore, '63
18	30	"	Fine cut granite	27.5	20.8	12.0	9.2	7.9	" " "
19	30	Portland	Sawed limestone	78	....	....	....	....	I. J. Mann, 1882
20	30	"	Cut granite	97	....	....	....	....	" " "
21	30	"	Polished marble	71	....	....	....	....	" " "
22	30	"	Bridgewater brick	66	....	....	....	....	" " "
23	30	"	Sandstone	49	....	....	....	....	" " "
24	30	Blue lias lime	Staffordshire brick	....	....	*40	....	....	Building News, '80
25	30	" " "	Gray stock brick	....	....	*36	....	....	" " "
26	30	" " "	Common soft brick	....	..	*18	....	....	" " "
27	30	Lime and pozzuolana	Hard brick	....	....	*5	....	....	J. White, 1832
28	42	Portland	Brick ¶	68.8	....	46.9	....	....	Bauschinger, 1873
29	48	"	" ¶	....	....	....	24.2	....	" "
30	56	"	" ¶	....	54	56.9	....	....	" "
31	90	Hydraulic lime	" †	39.3	41.9	38.9	28.1	22.6	Dr. Böhme, 1883
32	95	Portland	" ¶	....	....	....	14.2	....	Bauschinger, 1873
33	110	Hydraulic lime	" ¶	....	....	....	12.8	....	" "
34	180	Quicklime	"	....	....	*33	....	....	Rondolet, 1831
35	180	"	Limestone	....	....	*15	....	....	" "
36	180	"	Hard brick	....	....	*40	....	....	Robertson, 1858
37	180	"	Soft "	....	..	*18	....	....	" "
38	180	Portland	Sawed slate	62	....	....	....	....	I. J. Mann, 1883
39	180	"	Portland stone	55	....	....	....	....	" " "
40		"	Polished marble	75	....	....	....	....	" " "
41	270	Lime and pozzuolana	Hard brick	....	....	*8	....	....	J. White, 1832
42	320	Rosendale	Croton brick	68	40	24	....	....	Gen. Gillmore, '63
43	1 yr.	Quicklime	Not stated	....	....	....	*21	....	Vicat, 1818
44	"	Good quicklime	" "	....	....	..	*51	..	" "
45	"	Ordinary hydraulic lime	" "	....	....	*85	....	....	" "
46	"	Good " "	" "	....	....	*140	....	....	" "
47	"	" " "	Materials in air	....	70	....	....	....	Mallet, 1829
48	"	" " "	" " water	....	99	....	....	....	" "
49	"	Portland	Gault clay brick pressed	45	44	....	....	....	J. Grant, 1871
50	"	"	Stock brick in air	78	63	....	....	....	" " "
51	"	"	" " in water	96	70	....	....	....	" " "
52	"	"	Staffordshire blue brick in air	48	47	....	....	....	" " "
53	"	"	Staffordshire blue brick in water	40	29	....	....	....	" " "
54	"	"	Fareham red brick in air	126	83	....	....	....	" " "
55	"	"	Fareham red brick in water	123	62	....	....	....	" " "

* Proportions of sand not given, but presumably about those indicated in headings of table.
† Standard sand used in mixture. ‡ Clean river sand used in mixture.
§ Crushed sandstone used in mixture. ¶ Fine river sand used in mixture.
‖ Coarse particles in cement sifted out before testing.

501. Shearing Strength.—In recent times elaborate experiments to ascertain the shearing strength of mortar, both in the joints of brickwork and separate blocks, have been made by Prof. Bauschinger of Munich. The results are too numerous for a verbal description, and they are accordingly given in Table XLVI. None of the values obtained are very large, ranging after ninety days from 70 to 7 pounds per square inch on brickwork with mortar mixed in the proportion of three parts of relatively fine river sand to one of cement-lime. The shearing strength of cubes of mortar also appears to be considerably greater than that of the comparatively thin joints in brickwork, and to be influenced by the quality of the sand.

TABLE XLVI.

Shearing Strength of Cements and Mortars.

Age in Days when Tested.	Kind of Cement.	Average Shearing Strength in lbs. per sq. in.						Authority.
		Neat Cement.	Cement, 1. Sand, 1.	Cement, 1. Sand, 2.	Cement, 1. Sand, 3.	Cement, 1. Sand, 4.	Cement, 1. Sand, 5.	
	I. *Shear in, and parallel to, bed-joints of brickwork.*							
42	Portland (Bonn)*......	....	....	72.5	....	....	....	Prof. Bauschinger, 1873
49	" " *......	73.9	...	....	64	....	....	" " "
52	" " *......	....	155	106.6	....	....	....	" " "
90	" (Perlmoos)*.	....	....	....	22.7	....	....	" " "
90	Hydraulic lime*......	....	....	....	76.8	....	....	" " "
90	Quicklime*...........	....	....	....	7.1	....	...	" " "
	II. *Shear in cubes of cements and mortars dried in air.*							
50	Portland (Bonn)*.....	369.7	369.7	284.4	142.2	....	. ..	Prof. Bauschinger, 1873
60	" (Perlmoos)†.	256.0	405.3	383.9	362.6	320.0	....	" " "
1 w'k	‡ " " §.	224.7	....	....	108.1	...	66.8	" " 1878
"	‖ " " §.	301.5	....	....	123.7	....	78.2	" " "
2w'ks	‡ " " §.	270.2	....	....	128.0	....	93.9	" " "
"	‖ " " §.	322.8	....	....	163.5	....	122.3	" " "
4w'ks	‡ " " §.	257.4	....	....	153.6	....	112.3	" " "
"	‖ " " §.	341.3	..	....	199.1	....	137.9	" " "
8w'ks	‡ " " §.	258.8	...	....	196.2	....	167.8	" " "
"	‖ " " §.	376.8	....	....	237.5	....	199.1	" " "

* Fine river sand. † Coarse sand.

‡ Average values for series of four different brands of quick-setting cements.

§ Clean, medium sand.

‖ Average values for series of four different brands of slow-setting cements.

As in the case of adhesion, no exact relation between the tensile and the shearing strengths of mortar placed in brickwork can yet be deduced, owing to the lack of sufficient data; but, on the other hand, the experiments show that the shearing strength of blocks or cubes of mortar is about 20 per cent greater than the tensile strength under the same circumstances.

502. Compressive Strength.—But few experiments have been made upon the compressive strength of mortar. An examination of the results of about sixty experiments made with the Watertown testing-machine seems to show that the compressive strength of mortar, as determined by testing-cubes, is from 8 to 10 times the tensile strength of the same mortar at the same age. Data determined by submitting cubes of mortar to a compressive strain are of little or no value as showing the strength of mortar when employed in thin layers, as in the joints of masonry. The strength per unit of bed area increases rapidly as the thickness of the test-specimen decreases, but no experiments have ever been made to determine the law of this increase for mortar.

503. Tensile Strength.—The following table, carefully compiled from a large number of reliable experiments, gives the tensile strength of cement-mortar:

TABLE XLVII.

TENSILE STRENGTH OF CEMENT-MORTAR.

Composition of the Mortar.		Age of Mortar.							
		Rosendale.				Portland.			
Cement	Sand.	1 Week.	1 Month.	6 Months	1 Year.	1 Week.	1 Month.	6 Months	1 Year.
1	0	100	180	275	300	300	400	450	500
1	1	60	100	180	225	175	250	340	375
1	2	25	60	125	170	120	150	245	290
1	3	20	40	80	120	90	110	175	220
1	4	15	25	60	90	75	75	130	170
1	5	10	15	50	80	60	65	110	130
1	6	6	10	45	75	50	35	90	100

504. Fineness of Sand.—Vicat, in the course of elaborate experiments with limes and mortars in the early part of this century,

established standards for size of grain of what he termed coarse sand and fine sand, as follows; coarse sand being such as will pass through a sieve of 64 meshes per square inch and be retained on one of 289 meshes per square inch, while fine sand will pass through a sieve of 289 meshes per square inch and be retained on one of 625 meshes per square inch. On this definition he ranked the superiority of coarse, mixed, and fine sands with limes according to the following schedule:

For eminently hydraulic limes, 1, fine; 2, mixed; 3, coarse.

For slightly hydraulic limes, 1, mixed; 2, fine; 3, coarse.

For fat or quick limes, 1. coarse; 2, mixed; 3, fine.

It will suffice to say that with cement-mortars much better results are obtained when the sand is of the size of grain above described and is sharp and clean.

Mr. Clarke says that when the sand was formed of a mixture of fine and coarse grains nearly as good results were attained as with coarse grains alone.

Before leaving this subject it may be of interest to refer briefly to the experiments made at Wilhelmshaven in 1877 by H. Arnold, C.E., as published in the Journal of the Hanoverian Architects and Engineers' Society for 1883, and from which was found that the size of grain and quality of the sand used in Portland-cement mortar are important factors in its ultimate strength. With six different kinds of substantially clean sands and the same brand of cement mixed into mortar in the proportions of three volumes of sand to one volume of cement, the tensile strength after seven days ranged from 101 to 243 pounds per square inch, and after twenty-eight days from 133 to 311 pounds per square inch, thus exhibiting extremely wide variations, depending largely upon the size and roughness of the grains of sand.

In every instance it was found that a greater strength was developed with a coarse-grained sand free from very fine particles and dust than with a fine-grained sand, both being equally sharp. Mr. Arnold also points to the fact deduced from his experiments, that with the same cement but different sands of similar size of grain, the cohesion of the mortar may be found to vary considerably, and will probably depend upon the chemical composition of the sand. He therefore concludes that in order to obtain satisfactory results from the cement-mortar used in the construction of

public works, the quality of the sand available in the particular locality should first be taken into careful consideration.

If no other than a fine sand happens to be available and a given strength of the mortar is to be attained at the end of one week, experiments should be made to learn whether the proportions of sand to cement named in the specifications should be changed, since the strength diminishes rapidly with the quantity of sand used; and in such an event it may also be advisable to use an entirely different kind of cement. It is a necessary condition of success in mortar-making that every particle of the sand or "aggregate" be completely covered with the cement or "matrix;" and since, when the grains in a given volume are small, the magnitude of the total surface to be covered is greater than when the grains are large, it follows that fine sand requires a larger proportion of cement than coarse sand. Any specification or plan contemplating the use of a good coarse sand must, therefore, be altered if fine sand alone is used, or else the quality of the work will be impaired.

In support of the foregoing remarks, it has been quite generally observed by engineers that when most of our American natural cements are mixed entirely with fine sand the process of hardening is greatly retarded, even if not entirely prevented; while the same cements, when tested neat, exhibit a cohesive strength ranging from 50 to 136 pounds in twenty-four hours, thus showing conclusively the effect of admixing the fine material. An instructive instance of this kind was noticed some years ago, when an excellent quality of Akron "Star" cement was mixed with very fine sand from the Pinnacle pits in the proportion of 2½ parts sand to 1 part of cement. For several days the mass remained in a plastic state in the tin can in which it had been deposited, and upon being removed and exposed to the air upon a window-sill for several months it displayed very little strength and broke in handling. On the approach of cold weather the largest fragment was kept in an apartment constantly heated by steam, and after lying undisturbed therein for three months pieces could easily be broken off with the fingers. At the present time, after having attained an age of one year, it is still quite friable and entirely unfit for use. Another mass of mortar prepared at the same time from the same cement, but with clean, coarse sand, mixed in the proportions

of 3 parts of sand to 1 part of cement, indurated promptly and exhibited far better qualities.

TABLE XLVIII.

EFFECT OF SIZE OF GRAIN OF SAND ON TENSILE STRENGTH OF CEMENT-MORTAR.

Denomination of Size of Grains.	Tensile Strength of Mortar mixed 3 : 1 with			
	Dangast Sand after		Crushed Granite after	
	7 days.	28 days.	7 days.	28 days.
Hulled barley	177	218	194	255
Oatmeal	162	191	176	234
Standard	131	177	164	242
Grass-seed	134	164	144	192
Grit	141	160	136	193
Coarse dust, Fine dust	64	87	87	134

TABLE XLIX.

CHARACTER OF SIEVES FOR SIFTING SANDS.

Number of Sieve.	Number of Holes per lineal inch.	Number of Holes per square inch.	Size of Hole of Length of Side in inches.	Diameter of Wire in inches.
1	20	400	.03101	.01899
2	30	900	.02119	.01214
3	50	2500	.01119	.00881
4	80	6400	.00599	.00651
5	170	28900	.00309	.00279

505. Portland cement acquires its strength more quickly than Rosendale. Both cements, but especially the Rosendale, harden more and more slowly as the proportion of sand mixed with them increases; and whereas neat cement and rich mortars attain nearly their ultimate strength in six months or less, weak mortars continue to harden for a year or more. It has also been found that after a period of about a year weak mortars often lose in strength or tenacity what they may gain in hardness, from the fact of their

becoming brittle. Specimens of such mortar two years old break very irregularly. Mortars less than one month old are relatively weak, and hence the advantage of waiting as long as possible before loading masonry structures. Portland-cement mortars are especially useful in cases where the structure is necessarily subjected to severe strains within so short a period as one week, as frequently happens in the case of pavements.

506. Permeability of Mortar.—The permeability of mortar is increased as the proportion of the cement decreases. It increases with the coarseness of the sand. Mortars made with a mixture of sand of various sizes are relatively non-porous and non-permeable. Mortars mixed dry are more permeable than those mixed wet or of a "normal consistency."

507. Effect of Frost upon Mortars.—It is a matter of common knowledge that ordinary quick-lime mortar which is exposed to the action of frost before it has become well set or indurated will thereby become greatly injured in its adhesive and cohesive properties; and hence where such mortar is used it is customary to suspend all building operations on the arrival of the cold season. Should, however, it be necessary to proceed with the construction, experienced masons and builders sometimes make use of a quick-setting cement-mortar in place of lime, and cease work when the weather is at all severe. It is, therefore, of importance to learn something of the behavior of cements under such circumstances.

The impression seems to prevail quite extensively that cement-mortars are not appreciably injured by freezing, and that masonry may safely be constructed at any temperature below the freezing point at which a man can still work, provided that either brine or salt be used instead of fresh water, or that the materials be first heated. With regard to the use of brine or salt it may be remarked that whether the mortar will be injured thereby or not seems to depend principally upon the character of the cement. Most of the natural or "Roman" cements suffer a considerable loss of strength if mixed with salt water, while the Portland cements do not appear to be materially affected.

Respecting the practice of heating the cement, sand, and water before mixing, and then using the hot mortar in cold weather upon frosty stones or bricks, or depositing it in icy water, the experiments of William W. Maclay, C.E., submitted in 1877 to the American

Society of Civil Engineers, show indisputably that such a method of treatment is erroneous, and that a great amount of injury is effected when heated mortar, even if made of Portland cement, is immersed directly in cold water. The tests were all made with Burham Portland cement, which, when tested neat at ordinary temperature, gave a tensile strength of 278 pounds per square inch after seven days. In one series of experiments the ingredients of the mortar all had a temperature of about 40 degrees Fahr., and in another they were heated to 100 degrees Fahr. These two sets of briquettes were kept for seven days in precisely the same manner, and were broken on the same day, so that any changes in temperature during this period would necessarily affect them alike. The averages of the tensile strengths acquired show that by first heating the ingredients to about 100 degrees, then mixing them in air having a temperature of from 13 to 37 degrees, and afterward exposing the briquettes for six days to the winter weather, their strength in the case of neat cement was only from 7 to 20 per cent of that attained when the materials were mixed without heating, or with the temperature of the mortar at 40 degrees; and in the case of mortar mixed in the proportion of 2 sand to 1 cement, the tensile strength of the heated mortar after 28 days was only 30 per cent of that reached by the cold mortar at 40 degrees. From these and other similar experiments Mr. Maclay concludes that the mixing of cement-mortar with highly-heated materials for use above water in very low temperatures greatly reduces its normal strength, and that for use below icy water its value will thereby be almost entirely destroyed. If mortar must be used at all in such weather, it should be used cold, and the only condition to be observed is that the materials shall be free from frost at the time of using. "In the experiments where the materials were mixed cold and then exposed to the winter weather, Portland-cement mortar appeared to set without freezing even in as low a temperature as 13 degrees Fahr., except when it was windy; but where the briquettes were made of hot mortar they invariably froze, as was proven by their becoming soft again when the temperature rose."

Portland cement was found to possess the peculiarity, also noticed by many other writers on the subject, of setting in a low temperature wherein other varieties of cement will surely freeze. No definite limits of this action, however, have yet been assigned.

Mr. E. Leblanc exposed cakes of Portland-cement mortar to frost immediately after mixing and before any setting had occurred, with the result that "they cracked deeply and in part became disintegrated, but the detached fragments after being thawed were found perfectly hard." In Mr. Maclay's experiments none of the Portland-cement briquettes when mixed cold cracked in the slightest degree even when exposed to as low a temperature as 11 degrees Fahr., and they all became hard after thawing. This seems to be the prevailing opinion among engineers. Mr. J. Dutton Steele, C.E., in discussing the paper of Mr. Maclay, states that "cement-mortar is not seriously impaired by being laid in frost, as its property of setting is simply held in suspense during the time it remains frozen." Gen. Q. A. Gillmore, U.S.A., in his work on Beton, etc., remarks that "when the temperature is not much below the freezing point during the day, work may be safely carried on if care be taken to cover over the new material at night. After it has once set and has had a few hours to harden, neither severe frost nor alternate freezing and thawing has any effect upon it."

In the report of the work performed at the Royal Testing Laboratory of Berlin in 1886 there is an account of a number of experiments for ascertaining the effect of frost upon the strength of Portland cement, both neat and when mixed into mortar in the proportion of 3 parts of sand to 1 part of cement. These tests were made in two distinct series, the first one involving only a single exposure to frost on and during the sixth day after mixing, while in the second series the briquettes were treated as follows: First, allowed to indurate for twenty-four hours in the air of a warm room; second, exposed for twenty-four hours to a freezing temperature of from + 10 degrees to + 5 degrees Fahr.; third, thawed four hours in a warm room; fourth, placed under water until tested.

The experiments were made with six different brands of cement, and for each set of briquettes exposed to frost another similarly constituted set was kept in temperatures above the freezing point to serve as a basis of comparison of tensile strength. Upon testing the frozen and unfrozen samples, it was found that the effect of frost varied greatly with the quality of the cement; the loss in tensile strength incurred by such freezing ranging after seven days from 2 to 22 per cent in the case of neat cement, and from 3 to 24

per cent in the case of the mortar mixed as above described; also ranging after 28 days from 2 to 12 per cent in the case of neat cement, and from 1 to 33 per cent in the case of the mortar. It should be noted particularly that the foregoing results were derived when pure, clean, and standard materials only were used. On the other hand, where the cement was adulterated with 30 per cent of pulverized slag from a blast-furnace the loss in strength by freezing was much greater than above given, especially in the case of the mortar. After seven days this loss ranged from 6 to 62 per cent, and after 28 days from 21 to 44 per cent, standard sand having been used.

Other interesting experiments with regard to the effect of frost on Portland-cement mortar were carried out early in 1886 at Hamburg, Germany, by Mr. Moeller, C.E., and an account thereof is contained in the *Deutsche Bauzeitung* for November 17, 1886.

The results showed that Portland-cement mortar, whose time of setting is lengthened by the addition of sand or lime, or both, suffers severely in loss of tensile strength by the action of frost, and that such loss becomes greater as the proportion of sand or lime is increased; further, that a quick-setting Portland cement will indurate in spite of the frost, provided that it be protected therefrom for two days after having been tempered, and that it be as dry as possible before exposure to the cold. It was also found that the mixing of such materials with brine renders the mortar more capable of resisting the influence of frost, and that this statement likewise holds true for slow-setting compounds, such as 1 part of cement, 1 part of lime, and 3 parts of sand. Mortars thus prepared and mixed with fresh water instead of brine, and kept for two days at a temperature of + 41 degrees Fahr., and then exposed to the frost, lost nearly all strength, so that even after four months pieces could easily be broken off from the briquettes with the fingers; whereas when tempered with strong brine their strength after seven months was about fourteen times greater. Accordingly, if the mortar can be kept from freezing for a few days by the use of salt or brine, so as to allow the setting to take place, much benefit is sure to be derived.

It may also be deduced from these experiments that when it becomes absolutely necessary to lay masonry in freezing weather, quick-setting Portland cements, mixed with small proportions of

sand and water, should alone be employed; and when a satisfactory quality of work is expected or required, the use of brine or salt should be resorted to, as well as the protection of the newly-laid masonry at night by means of adequate coverings. In case, however, that the temperature is lower than 23 degrees Fahr. even these precautions will not prevent more or less damage.

Under such circumstances, moreover, it is self-evident that the stones or bricks should be free from snow or ice and as dry as practicable; also that all the materials, including the sand and cement, be free from frost by being kept at a temperature above the freezing point for some days before being used in the work. The safest rule, however, is to cease operations with mortars of any kind during the prevalence of frost.

In a paper read before the American Society of Civil Engineers in July, 1886, its author, Alfred Noble, C.E., states that "in the construction of the lock at the St. Mary's Falls Canal, the laying of masonry was discontinued about October 20 of each year, on account of the frequent recurrence of freezing weather. On the last day of the work done in 1877 mortars made of Portland cement and of a good quality of American natural cement were used in adjoining portions of the same wall. Both mortars were mixed in the proportions of 1 cement to 1 sand, and the masonry was laid during a light rain. The following spring the surface of the Portland-cement mortar was sound, showing perfectly the marks of the rain-drops, while the natural-cement mortar was disintegrated to a depth of three or four inches." Mr. Noble also mentions a few other cases where Portland-cement mortar was used in laying masonry during very cold weather without affecting the subsequent induration of the mortar noticeably. The inference to be drawn from his paper is that if it becomes imperative to use mortar in freezing weather, Portland cement should be used.

Similar effects of frost were also noticed by Mr. Francis Collingwood, C.E., on the Rosendale-cement mortars, mixed in the proportion of 2 sand to 1 cement, used for the masonry of the East River Bridge, since he states that "the tops of the various pieces of masonry were always gone over carefully in the spring. The concrete which had been put in late would usually be found disintegrated to a depth of from one to four inches, but below this it was found sound. The rule seems to be that it was unsound only

so far as it was exposed alternately to freezing and thawing; and wherever it had taken a set before freezing, and had not been thawed out for some time, it was sound." The experience of Mr. George S. Morison, C.E., with cements as given in his discussion of Mr. Noble's paper, was in full accord with what was therein stated, and in his extensive practice as a designer and builder of large bridges he uses Portland cement exclusively in all places where the mortar is liable to freeze before setting. Mr. Eliot C. Clarke, C.E., also mentioned that in experimenting with concretes of Rosendale and Portland cements which had been exposed to the weather for three years he found that the former was injured and disintegrated from year to year, while the latter were not affected at all.

Recent expressions of opinion from many other excellent authorities respecting the action of frost on cement-mortars are to the same effect as above recited. It is generally agreed that the freezing of freshly-prepared cement-mortar will not destroy its capacity to harden after becoming thawed, but exactly how much its cohesive and adhesive strength will thereby become impaired does not appear to be definitely known; neither is the effect of repeated freezing and thawing very clearly pointed out. In our winters it frequently happens that water freezes in the shade, while at the same time ice melts in the sunlight, and hence under such circumstances in a wall facing south a slow-setting mortar in the face will be alternately frozen and thawed, while that in the rear will continue to remain frozen. This condition of the work cannot fail to be prejudicial to its ultimate strength, and manifestly demands that a strong and quick-setting mortar be used if the laying of masonry be continued in freezing weather. Numerous instances of failure of walls and abutments built in winter may be cited which are fairly attributable to the thawing out of the frozen mortar after the warm weather has set in, whereby it becomes almost as soft as when first mixed. In such cases the thawed mortar acts rather as a lubricant than as an efficient binding material, and if the structure is then subjected to lateral forces of considerable magnitude, deformation or failure is sure to follow unless a very wide margin of safety has been allowed in the design. When, however, the dimensions are fixed with reference to economy and the use of ordinarily good materials and workmanship, as

generally happens, the action of frost becomes a very serious factor in the stability and durability of the work, and therefore care should be taken in the proper selection of the cement. It must always be remembered that frozen cement-mortar will not set so long as it remains frozen, and that when it becomes thawed it is simply in the condition of material freshly mixed, which, while in that state, imparts no more strength to the structure than sand, ashes, mud, or other inert matter.

A rather close observation for a number of years of the effects of frost on Buffalo and Akron cement-mortars, mixed in the proportion of two sand to one cement and three sand to one cement, leads to the conclusion that such mortars entirely disintegrate to a depth of several inches in exposed joints of masonry laid in cold weather; also that when used as coatings or renderings of rough stone surfaces a flaking thereof occurs by frost which leads to rapid disintegration. If it is imperative that masonry be built in freezing weather, a quick-setting Portland cement-mortar should be used, instead of such as is prepared with natural cements; also that even when Portland cement is used with brine, work should be suspended when the temperature is lower than 25 degrees Fahr., if good results are to be expected; and finally, smaller proportions of sand shoud be used than during the prevalence of higher temperatures.

508. The standard of tensile strength required by German engineers of Portland-cement mortar, prepared by mixing one unit of weight of cement with three like units of normal sand, and four tenths of such a unit of clean fresh water, and tested after an exposure of one day in air and twenty-seven days in water, is 227 pounds per square inch and a resistance to compression of 2300 pounds per square inch.

509. English Specifications for Portland Cement.—The following is a summary of the specifications used by Mr. Henry Faija, an accepted English authority:

Fineness.—To be such that the cement will pass through a sieve having 625 holes (25^2) to the square inch, and leave only 10 per cent residue when sifted through a sieve having 2500 holes (50^2) to the square inch.

Expansion or Contraction.—A pat made and submitted to

moist heat and warm water at a temperature of about 100 degrees Fahr. shall show no sign of blowing in twenty-four hours.

Tensile Strength.—Briquettes of slow-setting Portland, which have been gauged, treated, and tested in the prescribed manner, to carry an average tensile strain, without fracture, of at least 176 pounds per square inch at the expiration of three days from gauging; and those tested at the expiration of seven days to show an increase of at least 50 per cent over the strength of those at three days, but to carry a minimum of 350 pounds per square inch.

For quick-setting Portland at least 176 pounds per square inch at three days, and an increase at seven days of 20 to 25 per cent, but a minimum of 400 pounds per square inch. Very high tensile strengths at early dates generally indicate a cement verging on an unsound one."

510. Data for Estimates.—The following data will be found useful in estimating the amounts of the different ingredients necessary to produce any required quantity of mortar:

One barrel of lime (230 pounds) will make about 2¼ barrels (0.3 cubic yard) of stiff lime-paste. One barrel of lime-paste and three barrels of sand will make about three barrels (0.4 cubic yard) of good lime-mortar. One barrel of unslaked lime will make about 6.75 barrels (0.95 cubic yard) of one to three mortar.

A barrel of Portland cement weighs 400 pounds gross, or about 375 net. Hudson River Rosendale weighs 300 pounds net per barrel. Western Rosendale weighs 265 pounds net per barrel.

A barrel of Rosendale, as packed at the manufactories on the Hudson will measure from 1.25 to 1.40 barrels if measured loose. A barrel of Western Rosendale will make about 1.1 barrels if measured loose. A commercial barrel of Portland will make about 1.2 barrels if measured loose.

One cubic foot of dry cement (shaken down but not compressed) mixed with 0.33 cubic foot of water will give 0.63 cubic foot of stiff paste. One barrel (300 pounds) of finely ground Rosendale cement will make from 3.70 to 3.75 cubic feet of stiff paste; or 79 to 83 pounds of cement-powder will make about one cubic foot of stiff paste. Volume for volume, Portland will make about the same amount of paste as Rosendale; or 100 pounds of Portland will make a cubic foot of stiff mortar.

511. Machine-mixed mortars and concretes are superior to hand-

mixed. In hand-mixing the first drawback is the liability to error in measuring out correct and uniform proportions of prescribed materials. Mortar men make mistakes which generally happen to be against the proper proportions of cement. The quantity of sand will also vary according to whether it is measured in wet or dry condition, packed or loose. Next the workmen fail to intermix the cement and sand thoroughly before adding the water—an important point. Again, they will ease up on the labor required to mix all well together after applying water, and to facilitate the operation will over-dose the water. A further error occurs in assuming that all barrels of cement contain equal quantities. The necessity of a close supervision will be recognized in these particulars.

512. Specifications for Concrete (Boston).—The American cement-concrete shall be made of one part of American hydraulic cement, two parts of clean, sharp sand, and five parts of clean broken stone or screened gravel-stones by measure.

The Portland-cement concrete shall be made of one part Portland cement, three parts of clean, sharp sand, and seven parts of clean broken stone or screened gravel-stones by measure.

The stone for the concrete shall be free from clay, dirt, or other objectionable material; no stone shall be larger than 2½ inches and but very few less than ½ inch in their greatest dimensions.

The mixing shall be done in proper boxes, in a manner satisfactory to the engineer; and after the materials are wet the work must proceed rapidly until the concrete is in place and is so thoroughly rammed that water flushes to the furface and all the interstices between the stones are entirely filled with mortar. The surface of the concrete foundation must be floated and made exactly parallel with the crown of the pavement to be laid, and must be suitably protected from the action of the sun and wind until set. It shall be allowed to set a sufficient time, to be determined by the engineer, before walking over or working upon it shall be allowed.

513. Specifications for Concrete (Berlin).—The concrete is to be prepared from a mixture of cement and sand or a mixture of cement, sand, and broken granite or limestone. In making it at least one barrel of cement in the standard proportion of 180 kilos gross or 70 kilos net weight is to be used with one cubic meter of sand or of sand and stone. The proportions of sand and broken stone are to be determined in each case by the inspector. If in exceptional

cases a greater proportion of cement is employed to obtain quicker setting, a corresponding payment will be made for each barrel used, as given in the schedule of prices.

The cement is to be weighed whenever the inspector desires. In order that the proportions may exactly conform to the specifications, the sand or mixture of sand and stone is to be measured in boxes holding exactly one half or one cubic meter.

The mixing is done on a platform that must be 30 centimeters (11.8 inches) larger all around than the bottom of the measuring-boxes. The sides are to be provided with strips to prevent the falling of the material. In order to insure regular work at least five mixing-boards are to be set up at each place fo working.

Sand and cement are to be twice mixed dry before water is added. After the addition of the water the mass must be immediately worked to a stiff condition. During the preparation of the concrete, all the foreign bodies in the cement or sand are to be carefully removed. If, during the process of mixing, a portion of the concrete, of sand or stone, falls from the platform, it must not be again added to the mass and used in the concrete, but must be removed.

Laying the Concrete.—In order to insure the exact formation of the concrete foundation, a series of templates are to be laid on the road-bed from 4 to 5 meters apart and parallel to the axis of the street. The greatest care must be taken to have these templates at the proper height, and all out of alignment must be immediately removed.

When the road-bed has been finally brought to the proper grade the concrete is to be laid between the templates and thoroughly tamped and worked into a profile corresponding to that of the finished street surface.

Use of the Concrete after its Preparation.—While the concrete is setting, it is to be sprinkled with water so that the surface is continually moist, and as long as it remains soft the work must be protected by suitable guards from intruders.

No concrete shall be prepared at a temperature below 2 degrees Réaumur (36½ degrees Fahr.). Concrete just laid is to be protected for two days, when frost begins, by a covering of mats or bundles of straw.

The foundation must have exactly the same profile as the upper

surface of the finished pavement is to receive. It is especially necessary that the surface be free from all inequalities, elevations as well as depressions. Work must not begin on the construction of the foundation until the inspector has definitely stated that the work on the roadbed has been finished in the manner prescribed in the regulations.

514. Specifications for Concrete (New York).—One part of American cement, equal to the best quality of freshly burned Rosendale cement, two parts of clean, sharp, washed sand, free from clay, to be thoroughly mixed dry and then made into mortar with the least possible amount of water; to this shall be added three parts of sound stone, broken with a hammer, the largest of which will pass through a 2-inch ring, the broken stone to be wet before being added to the mortar. The whole mass shall then be shoveled over until it is thoroughly mixed before it is put in place; it shall then be put in place and rammed until it is thoroughly compacted and has a clean mortar surface.

The whole operation of mixing and laying each batch will be performed as expeditiously as possible, by the employment of a sufficient number of skilled men.

The upper surface will be made exactly parallel with the pavement when laid, and, if necessary, will be protected from the action of the sun and wind until set.

No concrete will be allowed to be used which has been mixed more than three hours.

The concrete shall be laid to a depth of 6 inches.

515. Concrete for Foundations, as used in Paris.—The proportions by bulk are:

Cement	1	part
Sand	4	parts
Gravel	6	"
Water	1½	"

or one of cement to ten of sand and gravel.

The concrete is mixed on a large mortar-board, the mixers moving the board ahead as the work advances, and never being more than a few feet from the spot where the concrete is to be placed.

A square wooden form is placed on the mortar-board; into this is dumped successively, in the order named, 2 barrows of gravel,

½ sack of cement, 1 barrow of gravel, ½ sack of cement, 2 barrows of sand. The form is then removed, and the mass turned over dry with the shovel by two men working side by side. It is then turned a second time by the two men, while a third sprinkles on the water from a pot. The mass is then turned over a third time, and shoveled from the board directly into place.

This concrete sets quickly, and every evening the surface of that laid during the day is covered with a thin coat of pure cement.

516. Specifications for Preparation of Roadbed.—The subsoil or other matters (be it earth, rock, or other material) shall be excavated and removed to a depth of   inches below the top line of the proposed pavement. Should there be any spongy material, vegetable or other objectionable matter, in the bed thus prepared, all such material must be entirely removed, and the space filled with clean gravel or sand carefully rammed.

The roadbed shall be truly shaped and trimmed to the required cross-section and grade, and rolled to ultimate resistance with a roller weighing not less than ten tons; such portions of the road-bed as cannot be reached by the roller shall be consolidated with hand rollers or tampers.

Note.—The employment of ashes, garbage, or other objectionable matter should not be permitted for filling on the streets of cities and towns.

Rock shall be excavated to a depth of 2 feet below the level of the finished grade, and the space so excavated shall be refilled to subgrade level with gravel, steam ashes, or other approved material, and thoroughly consolidated.

CHAPTER X.

RESISTANCE TO TRACTION.

517. The resistance to traction on highways is occasioned (1) by the want of uniformity in the surface of the road, the weight of the load having to be lifted over the projecting points and out of hollows and ruts, thus diminishing the effective load which the horse may draw to such as it can lift.

(2) The want of strength of the roadbed itself, however free its surface may be from asperities or cavities, if its substructure be of such a nature that it will yield to the pressure of the wheels, adds another impediment to the movement of a load over it, with the additional disadvantage that while the horse is endeavoring to lift the load from a cavity or hollow, the fulcrum, which in the first case was supposed to be fixed and rigid, is in the latter yielding and variable, subjecting the horse to the constant effort of lifting, instead of simply drawing.

518. Want of Uniformity in the Surface.—The power required to draw a wheel over a stone or any obstacle, such as S in Fig. 36, may be thus calculated. Let P represent the power sought, or

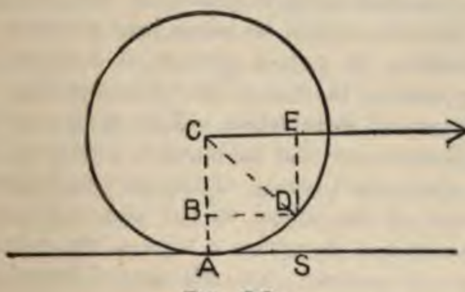


FIG. 36.

that which would just balance the weight on the point of the stone, and the slightest increase of which would draw it over.

This power acts in the direction CP with the leverage of BC or DE. Gravity, represented by W, resists in the direction CB with the leverage of BD. The equation of equilibrium will be $P \times CB = W \times BD$, whence

$$P = W\frac{BD}{CB} = W\frac{\sqrt{CD^2 - BC^2}}{CD - AB}$$

Let the radius of the wheel $= CD = 26$ inches, and the height of the obstacle $= AB = 4$ inches. Let the weight $W = 500$ pounds, of which 200 pounds may be the weight of the wheel and 300 pounds the load on the axle. The formula then becomes

$$P = 500\frac{\sqrt{676 - 484}}{26 - 4} = 500\frac{13.85}{22} = 314.7 \text{ pounds.}$$

The pressure at the point D is compounded of the weight and the power, and equals

$$W\frac{CD}{CB} = 500 \times \frac{26}{22} = 591 \text{ pounds,}$$

and therefore acts with this great effect to destroy the road in its collision with the stone, in addition there is to be considered the effect of the blow given by the wheel in descending from it. For minute accuracy the non-horizontal direction of the draught and the thickness of the axle should be taken into account. The power required is lessened by proper springs to vehicles, by enlarged wheels, and by making the line of draught ascending.

519. Resistance of Penetration.—This resistance is that of a medium distributed over the submerged portion of the circumference of a wheel, in advance of the perpendicular line drawn from the centre of the wheel to the plane of the road. The following investigation furnishes a formula for calculating, with sufficient degree of accuracy, the resistance of gravel, loose stones, soft earth, or clay.

Let AOB, Fig. 37, be a wheel drawn over the horizontal surface CDE of the road, in the direction OF, and let the road be of such a consistency that the wheel penetrates to the depth

DB below the surface, leaving a track *BG* behind it. The arc *BC* is the submerged portion of the circumference, and it may be assumed to be identical with the chord of the arc *BC*. Now the resistance is distributed over the surface *BC*, and it may be taken

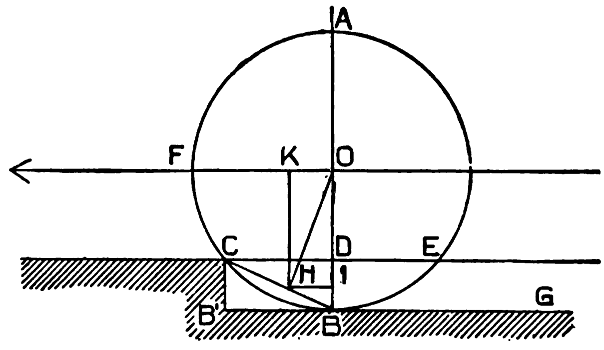


FIG. 37.

as acting on this surface perpendicularly to the plane of the road, or vertically and directly opposed to the gross weight, consisting of the weight of the wheel and the load upon it. To simplify the investigation, let it be supposed that the upper portion of the road is homogeneous, as clay or sand; then the resistance to penetration is nothing at the surface, and it increases as the depth; and the upward resistance along the line of submersion, *BC*, is a maximum at *B* and it vanishes at *C*, and the varying intensity of the graduated pressure may be represented by an isosceles triangle, of which the centre of gravity, *H*, situated at one third of its length, *BH*, from the base, *B*, is also the centre of resistance, and therefore also the centre of pressure under the load; and the radial line *OH* is the resultant of the pressure of the load, measured in force and direction by the vertical *OI*, and the tractive force, measured by the horizontal line *HI* or *OK*. But the vertical *OI* may be taken as equal to the radius *OB*, and the horizontal *HI* may be taken as one third of the semi-chord of submersion *CD*; whence the proportion

Load : tractive force :: *OB* : *CD* :: radius of wheel : $\frac{1}{3}$ semichord;

and the resistance to traction is equal to the product of the load by the third of the semichord divided by the radius of the wheel.

But the length of the semichord CD may be more easily determined by calculation from the measured depth of submersion DB. It is equal to the square root of the products of the segments into which the diameter AB is divided by the plane of the road CDE, or to $\sqrt{AD \times DB}$; and the whole of the calculations is embraced by the equation

$$\text{Tractive force } OK = \tfrac{1}{3} \times \frac{W\sqrt{AD \times BD}}{OB} \quad . \; . \; . \; . \; (1)$$

The work done in compressing the material of the road is easily indicated diagrammatically, by supposing the wheel to advance through a space equal to the semichord CD, or the length of the submersion. Thus, in Fig. 38, the wheel AB is supposed to roll

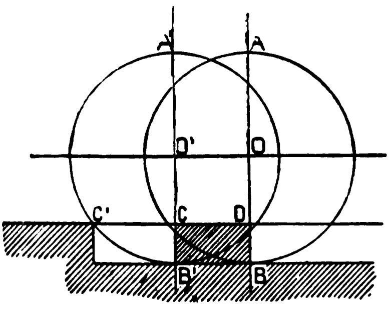


FIG. 38.

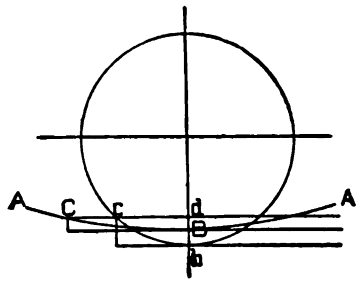


FIG. 39.

forward and to occupy the position $A'B'$. The work done in compressing the road is proportioned to the four-sided area $BCC'B'$, comprised between the circumferential segments BC and $B'C'$, and this area is, by the properties of the circle, equal to the original rectangular area $BDCB'$.

Now, suppose a wheel ABA, Fig. 39, of larger diameter with the same gross weight, to travel over the same surface. It is obvious that, if it could sink to the same depth, db, as that for the smaller wheel, the length of immersion, dc, would be increased, and the rectangle, $db \times dc$, representing work, would be greater

than that performed by the smaller wheel in the first example. Such a supposition cannot be admitted: the depth of immersion, dB, for the larger wheel, must be less than that, db, for the smaller wheel, though the length of immersion dC, must be greater than that dc, for the smaller wheel, but not so much greater as if the wheel were sunk to the first depth, db.

In fine, larger wheels sink less but spread more into the surface than the smaller wheels, in such proportion that the area of the rectangle representing work of submersion is constant for all sizes of wheels. In this instance, accordingly, the rectangle $db \times dc =$ the rectangle $dB \times dC$.

It might be thought that, on this principle of the constancy of the work of submersion, in a soft road, the resistance to traction must be the same for all diameters of wheels. But, as the rectangle of work is spread over a longer space, dC, for the larger wheel, than the space, dc, for the smaller wheel, it follows, on the contrary, that the resistance or force of traction varies in some proportion inversely as the diameter, being less as the diameter is greater. This conclusion accords with experience; but though the actual law of variation may not be strictly deducible in the line of reasoning here traced, it is nevertheless useful to carry the reasoning to its logical conclusion. Let a and A be the diameters respectively of the smaller and the larger wheels, b and B the depths of immersion, and c and C the lengths of immersion, or dc and Dc, respectively. As already stated, the areas of immersion are equal to each other, or

$$bc = BC. \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (2)$$

Also, the values of c and C are, by the properties of the circle, expressible by the products $\sqrt{ab}$ and $\sqrt{AB}$, for all cases that need occur in practice; and, by substitution in the equation (2),

$$b\sqrt{ab} = B\sqrt{AB}; \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (3)$$

and, squaring both sides,

$$ab^3 = AB^3. \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (4)$$

Finally, extracting the cube root of each side of this equation (4), the equation (5) is obtained,

$$b\sqrt[3]{a} = B\sqrt[3]{A}, \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (5)$$

which may be developed into the proportion

$$b : B :: \sqrt[3]{A} : \sqrt[3]{a}; \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (6)$$

showing that the depth of immersion varies as the cube root of the diameter. But, as $bc = BC$, and $b : B :: C : c$, then,

$$C : c :: \sqrt[3]{A} : \sqrt[3]{a}, \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (7)$$

showing that the length of immersion is as the cube root of the diameter. It has already been seen that the force of traction is as the length of immersion; therefore, finally,

520. The circumferential or rolling resistance of wheels to traction on a level road is inversely proportional to the cube root of the diameter.

On this principle of resistance, it follows that, to reduce the rolling resistance of a wheel one half, for instance, the diameter must be enlarged to eight times the primary diameter.

The deduction of M. Morin, that the resistance varies simply in the inverse ratio of the diameter of the wheel,—so that, for example, a wheel of twice the diameter would only incur half the resistance,—has been generally accepted. But this deduction is not supported by the foregoing analysis of forces, and there is good reason for renouncing it, in the more recent experiments of M. Dupuit. He placed model wheels or rollers of various diameters at the summit of an inclined plane, succeeded by a horizontal plane, on which they rolled down by the force of gravity and arrived at a state of rest after having expended the energy acquired in falling through the height of the plane. From these and other experiments he drew the following deductions:

On macadamized roads in good condition, and on uniform surfaces generally,

(1) The resistance to traction is directly proportional to the pressure.

(2) It is independent of the width of the tire.

(3) It is inversely as the square root of the diameter.

(4) It is independent of the speed.

M. Dupuit admits that on paved roads which give rise to constant concussion, the resistance increases with the speed, whilst it is diminished by an enlargement of the tire up to a certain limit.

The resistance produced by the hollows between the stones of a pavement is of a different character. According to M. Gerstner, the resistance arising from such a surface is directly proportional to the load, to the square of the velocity, and to the ratio of the width of the cavity to the radius of the wheel, and inversely proportional to the width of the paving-stones.

521. Friction.—The resistance of friction arises from the rubbing of the wheels against the surfaces with which they come in contact, and will always exist. The friction of surfaces is variable, and can be determined only by experiment. Friction of the axles and resistance of the air are causes of resistance to motion but their consideration may be neglected, as their effects are constant, and independent of the imperfections of the road.

522. Many experiments have been made at various times to ascertain, in functions of the quality and condition of the road-surfaces, the measure of the tractive force, or the force required to overcome the resistances which oppose themselves to the movement of a vehicle along horizontal roads of different degrees of smoothness and hardness and covered with different materials.

Table L presents the results of those experiments. The frac-

TABLE L.

RESISTANCE TO TRACTION ON DIFFERENT ROAD-SURFACES.
(RUDOLF HERING).

Character of Road.	Resistance in Terms of Load.	Pounds per ton.	Velocity.	Authority.
Sand	$\frac{1}{5}$	448	Pace	Bevan
Sandy road................	$\frac{1}{12}$	187	3′ to 12′ per sec.	Morin
Gravel (loose).............	$\frac{1}{7}$	320	Pace	Bevan
" (4 in. thick)........	$\frac{1}{10}$	224	"	Morin
" (common road).....	$\frac{1}{16}$	140	"	Macheil
" (road)...............	$\frac{1}{26}$	86	3′ per sec.	Rumford
" "	$\frac{1}{25}$	90	12′ per sec.	"

RESISTANCE TO TRACTION ON DIFFERENT ROAD-SURFACES—*Continued.*

Character of Road.	Resistance in Terms of Load.	Pounds per ton.	Velocity.	Authority.
Gravel (hard rolled)........	[illegible]	75	Pace	Bevan, Minard
Turf (wet)........	$\frac{1}{8}$	280	"	Morin
" (dry and hard)........	[illegible]	134	"	"
" " " "........	[illegible]	90	....	Bevan
Earth (ordinary road)......	[illegible]	224	Pace	"
Earth (dry and hard)......	[illegible]	101–75	"	Morin
Clay (hard)............	[illegible]	112	....	Bevan
Cobblestones (ordinary)....	$\frac{1}{8}$	280	Trot	....
" "	[illegible]	140	Pace	....
" (good, 3½ in.).	[illegible]	150	Trot	Kossack
" " "	[illegible]	75	Pace	"
Macadam (little used)......	[illegible]	140–97	....	Morin
" (bad)............	$\frac{1}{14}$	160	Pace	Gordon
" (old)..........	[illegible]	90	....	Navier
" (ordinary)........	[illegible]	90	Trot	MacNeil, Perdon't
" "	[illegible]	64	Pace	Kossack
Macadam (good, slightly [illegible])........	[illegible]	75–41	....	Morin
Macadam (best French)......	[illegible]	45	....	Navier
Macadam (very hard and smooth)............	[illegible]	45	....	MacNeil
Macadam (best)............	[illegible]	64	Trot	Rumford
" "	[illegible]	50	Pace	"
" "	[illegible]	48–37	....	Gordon
" "	[illegible]	52–30	....	Morin
[illegible] block (ordinary)..	[illegible]	56	Pace	MacNeil
[illegible] block ([illegible], Paris)..	[illegible]	50–34	....	Navier
" " (good)......	[illegible]	75	Trot	Rumford
" "	[illegible]	37	Pace	"
" " ([illegible])......	[illegible]	35	....	MacNeil
" " (good)......	[illegible]	50–26	....	Morin
[illegible] block (ordinary)..	[illegible]	90	....	Perdon't, Poncelet, Minard
" " (good)......	[illegible]	132	Trot	Rumford
" "	[illegible]	45	Pace	"
" " (good [illegible])......	[illegible]	36	....	Gordon
Plank roadway......	[illegible]	56–40	....	Morin
Asphalt............	[illegible]	17	....	Gordon
Granite tramway........	[illegible]	14	....	"
Iron tramway........	[illegible]	11	....	"
Sledges on snow [illegible] in. thick [illegible] compressed [illegible]......	[illegible]	75	....	....

tions which are generally rounded off, indicate the part of the whole weight which is equivalent to the resistance of drawing it on a level road. An examination of this table will clearly show the great economy in horse-power by using the hardest and smoothest material for road-coverings. For instance, if 1 horse can just draw a load on a level road on iron rails, it will require $1\frac{1}{2}$ horses to draw it on asphalt, $3\frac{1}{3}$ on the best Belgian-block pavement, 7 on good cobblestone pavement, 13 on bed cobblestone, 20 on an ordinary earth road, and 40 on a sandy road.

523. The following deductions are from the experiments of MM. Dupuit and Morin:

1st. The resistance to traction on uniform smooth surfaces is directly proportional to the load, and inversely as the square root of the diameter of the wheels.

2d. It is independent of the width of the tire when this quantity exceeds 3 or 4 inches.

3d. It is independent of the speed.

4th. On paved surfaces which give rise to constant concussion, it increases with the speed.

5th. Upon soft roads of earth or sand or turf, or roads fresh and thickly gravelled, the resistance to traction is independent of the velocity.

6th. At a walking pace, the resistance is the same, under the same circumstances, for vehicles with springs and for vehicles without springs.

7th. The destruction of the road is, in all cases, greater as the diameter of the wheels is less, and it is greater in vehicles without than with springs.

524. The comparative ease of draft on various surfaces is largely influenced by the amount of foothold afforded, and it may be doubted if dynamometer experiments, however carefully made, are altogether conclusive. The tractive force is influenced by the diameter of the wheels, the friction of the wheels on the axles, and the speed, as well as by the resistance of the road surface; and these must be all taken into account to obtain accurate results. Recent experiments on London and Paris street pavements gave the following results, speed 2 to 6 miles per hour:

TABLE LI.

TRACTIVE FORCE ON A LEVEL.

Surface.	Pounds per ton.	
	London.	Paris.
Macadamized	40.7 to 44.29	32.12 to 39.38
Asphalt	39.0 " 39.32	....
Wood	33.62 " 36.03	33.44 to 39.16
Granite	26.2 " 27.00	35.20

525. Gravity.—The grade of the road, or the quantity by which it differs from a level. The grade resistance is due to the force of gravity, and is the same on both good and bad roads, and unlike the others may be determined from the laws of mechanics, whilst the former are determinable entirely by experiment on the road in question. The resistance due to gravity on any incline in pounds per ton $= \dfrac{2240}{\text{rate of grade}}$.

TABLE LII.

RESISTANCE DUE TO GRAVITY ON DIFFERENT INCLINATIONS.

Grade 1 inch	20	30	40	50	60	70	80	90	100	200	300	400
Rise in feet per mile	264	176	132	105	88	75	66	58	52	26	17	13
Resistance in lbs. per ton	112	74½	56	45	38	32	28	25	22	11¼	7½	5¼

526. The additional resistance caused by inclines may be investigated in the following manner: Suppose the whole weight to be borne on one pair of wheels, and that the tractive force is applied in a direction parallel to the surface of the road.

Let AB in Fig. 40 represent a portion of the inclined road, C being a vehicle just sustained in its position by a force acting in the direction CD. It is evident that the vehicle is kept in its position by three forces; namely, by its own weight W acting in the vertical direction CF, by the force F applied in the direction CD parallel to the surface of the road, and by the pressure P which the vehicle exerts against the surface of the road acting in the direction CE perpendicular to the same. To determine the relative magnitude

of these three forces, draw the horizontal line AG and the vertical one BG; then, since the two lines CF and BG are parallel and are

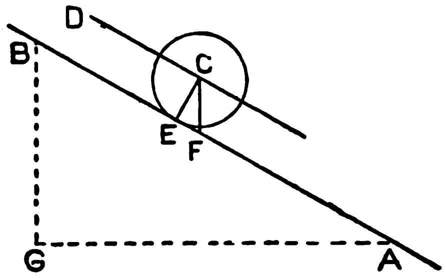


FIG. 40.

both cut by the line AB, they must make the two angles CFE and ABG equal; also the two angles CEF and AGB are equal; therefore the remaining angles FCE and BAG are equal, and the two triangles CFE and ABG are similar. And as the three sides of the former are proportional to the three forces by which the vehicle is sustained, so also are the three sides of the latter; namely, AB or the length of the road is proportional to W, or the weight of the vehicle; BG, or the vertical rise in the same, to F, or the force required to sustain the vehicle on the incline; and AG, or the horizontal distance in which the rise occurs, to P, or the force with which the vehicle presses upon the surface of the road. Therefore

$$W : AB :: F : GB,$$

and

$$W : AB :: P : AG.$$

And if to AG such a value be assigned that the vertical rise of the road is exactly one foot, then

$$F = \frac{W}{AB} = \frac{W}{\sqrt{AG^2 + 1}} = W.\sin A,$$

and

$$P = \frac{W.AG}{AB} = \frac{W.AG}{\sqrt{AG^2+1}} = W.\cos A,$$

in which A is the angle BAG.

527. To find the force requisite to sustain a vehicle upon an inclined road (the effects of friction being neglected), divide the weight of the vehicle and its load by the inclined length of the road, the vertical rise of which is one foot, and the quotient is the force required.

528. To find the pressure of a vehicle against the surface of an inclined road, multiply the weight of the loaded vehicle by the horizontal length of the road, and divide the product by the inclined length of the same; the quotient is the pressure required.

529. The force with which a vehicle presses upon an inclined road is always less than its actual weight; the difference is so small that, unless the inclination is very steep, it may be taken equal to the weight of the loaded vehicle.

530. To find the resistance to traction in passing up or down an incline, ascertain the resistance on a level road having the same surface as the incline, to which add, if the vehicle ascends, or subtract, if it descends, the force requisite to sustain it on the incline; the sum or difference, as the case may be, will express the resistance.

531. Tractive Power and Gradients.—The necessity for easy grades is dependent upon the power of the horse to overcome the resistance to motion composed of the four forces, friction, collision, gravity, and the resistance of the air.

All estimates on the tractive power of horses must to a certain extent be vague, owing to the different strengths and speeds of animals of the same kind, as well as to the extent of their training to any particular kind of work. Authorities on the subject differ widely, and sometimes express themselves in a loose manner that throws doubt on their meaning.

532. The draught or pull which a good average horse, weighing 1200 pounds, can exert on a level, smooth road at a speed of $2\frac{1}{2}$ miles per hour is 100 pounds, equivalent to 22,000 foot-pounds per minute, or 13,200,000 foot-pounds per day of 10 hours.

533. The tractive power diminishes as the speed increases and perhaps, within certain limits, say from $\frac{3}{4}$ to 4 miles per hour, nearly

in inverse proportion to it. Thus the average tractive force of a horse, on a level, and actually pulling for 10 hours, may be assumed approximately as follows:

TABLE LIII.

TRACTIVE POWER OF HORSES AT DIFFERENT VELOCITIES.

Miles per hour.	Tractive Force. Pounds.	Miles per hour.	Tractive Force. Pounds.
$\frac{3}{4}$	333.33	$2\frac{1}{4}$	111.11
1	250	$2\frac{1}{2}$	100
$1\frac{1}{4}$	200	$2\frac{3}{4}$	90.91
$1\frac{1}{2}$	166.66	3	83.33
$1\frac{3}{4}$	142.86	$3\frac{1}{2}$	71.43
2	125	4	62.50

534. The work done by a horse is greatest when the velocity with which he moves is $\frac{1}{3}$ of the greatest velocity with which he can move when unloaded; and the force thus exerted is 0.45 of the utmost force that he can exert at a dead pull.

TABLE LIV.

DURATION OF A HORSE'S DAILY LABOR AND MAXIMUM VELOCITY UNLOADED.

Duration of Labor. Hours.	Maximum Velocity. Miles per hour.	Duration of Labor. Hours.	Maximum Velocity. Miles per hour.
1	14.7	6	6.0
2	10.4	7	5.5
3	8.5	8	5.2
4	7.3	9	4.9
5	6.6	10	4.6

535. The tractive power of a horse may be increased in about the same proportion as the time is diminished, so that when working from 5 to 10 hours, on a level, it will be about as shown in the following table:

TABLE LV.

Hours per day.	Traction (pounds).	Hours per day.	Traction (pounds).
10	100	7	$146\frac{6}{7}$
9	$111\frac{1}{9}$	6	$166\frac{2}{3}$
8	125	5	200

Table LVI is useful as showing the maximum amount of labor a horse of average strength is capable of performing at different rates of speed.

TABLE LVI.

Speed in Miles per hour.	Duration of the Day's Work.	Resistance to Traction.	Useful Effect of One Horse working 1 day in tons drawn 1 mile.	
			On Level Iron Rails. Tons.	On Level Macadam. Tons.
2½	11½	83⅓	115	14
3	8	83⅓	92	12
3½	5 9/10	83⅓	82	10
4	4½	83⅓	72	9
5	2 9/10	83⅓	57	7.2
6	2	83⅓	48	6.0
7	1½	83⅓	41	5.1
8	1⅛	83⅓	36	4.5
9	9/10	83⅓	32	4.0
10	¾	83⅓	28.8	3.6

536. Loss of Tractive Power on Inclines.—In ascending inclines a horse's power diminishes rapidly; a large portion of his strength is expended in overcoming the resistance of gravity due to his own weight and that of the load. Table LVIII shows that as the steepness of the grade increases the efficiency of both the horse and the road-surface diminishes; that the more the horse's energy is expended in overcoming gravity the less remains to overcome the surface-resistance.

Table LVII shows the gross load which an average horse,

TABLE LVII.

Description of Surface.	Level.	5 per cent. Grade.	10 per cent. Grade.
	Pounds.	Pounds.	Pounds.
Asphalt..............................	13,216	.....	....
Broken stone (best condition)..........	6,700	1,840	1,060
" " (slightly muddy).........	4,700	1,500	1,000
" " (ruts and mud)..........	3,000	1,390	890
" " (very bad condition).....	1,840	1,040	740
Earth (best condition).................	3,600	1,500	930
" (average condition).............	1,400	900	660
" (moist but not muddy)..........	1,100	780	600
Stone-block pavement (dry and clean).	8,300	1,920	1,090
" " " (muddy).......	6,250	1,800	1,040
Sand (wet)...........................	1,500	675	390
" (dry)............................	1,087	445	217

weighing 1200 pounds, can draw on different kinds of road-surfaces, on a level and on grades rising five and ten feet per one hundred feet.

537. The decrease in the load which a horse can draw upon an incline is not due alone to gravity; it varies with the amount of foothold afforded by the road-surface. The smoother the surface the less the foothold, and consequently the load. Table LVIII shows the decrease in the loads caused by various road-coverings on grades from 1 to 20 per cent.

TABLE LVIII.

EFFECT OF GRADES UPON THE LOADS A HORSE CAN DRAW ON DIFFERENT PAVEMENTS.

Grade.	Earth.	Broken Stone.	Stone Blocks.	Asphalt.
Level	1.00	1.00	1.00	1.00
1 : 100	.80	.66	.72	.41
2 : 100	.66	.50	.55	.25
3 : 100	.55	.40	.44	.18
4 : 100	.47	.33	.36	.13
5 : 100	.41	.29	.30	.10
10 : 100	.26	.16	.14	.04
15 : 100	.10	.05	.07	....
20 : 100	.04	....	.03	....

538. The loss of tractive power on inclines is greater than any investigation will show; for, besides the increase of draught caused by gravity, the power of the horse is much diminished by fatigue upon a long ascent, and even in greater ratio than man, owing to its anatomical formation and great weight. Though a horse on a level is as strong as five men, on a grade of 15 per cent, it is less strong than three; for three men carrying each 100 pounds will ascend such a grade faster and with less fatigue than a horse with 300 pounds.

539. A horse can exert for a short time twice the average tractive pull which he can exert continuously throughout a day's work; hence, so long as the resistance on the incline is not more than double the resistance on the level, the horse will be able to take up the full load which he is capable of drawing.

540. Steep grades are thus seen to be objectionable, and particularly so when a single one occurs on an otherwise comparatively level road, in which case the load carried over the less inclined portions must be reduced to what can be hauled up the steeper portion.

541. The bad effects of steep grades are especially felt in winter, when ice covers the roads, for the slippery condition of the surface causes danger in descending, as well as increased labor in ascending; the water of rains also runs down the road and gulleys it out, destroying its surface, thus causing a constant expense for repairs. The inclined portions are subjected to greater wear from the feet of horses ascending, thus requiring thicker covering than the more level portions, and hence increasing the cost of construction.

542. It will rarely be possible, except in a flat or comparatively level country, to combine easy grades with the shortest and most direct route. These two requirements will often conflict; in such a case increase the length. The proportion of this increase will depend upon the friction of the covering adopted. But no general rule can be given to meet all cases as respects the length which may thus be added, for the comparative time occupied in making the journey forms an important element in any case which arises for settlement. Disregarding time, the horizontal length of a road may be increased, to avoid a 5 per cent grade, seventy times the height.

Table LIX shows with sufficient exactness for most practical

TABLE LIX.

Rate of Grade. Feet per 100 feet.	Pressure on the Plane in lbs. per ton.	Tendency down the Plane in lbs. per ton.	Power in lbs. required to haul one ton up the Plane.	Equivalent Length of Level Road. Miles.	Maximum Load in lbs. which a Horse can haul.
0.0	2240	00	45.00	1.000	6270
0.25	"	5.60	50.60	1.121	5376
0.50	"	11.20	56.20	1.242	4973
0.75	"	16.80	61.80	1.373	4490
1	* "	22.40	67.40	1.500	4145
1.25	"	28.00	73.00	1.622	3830
1.50	"	33.60	78.60	1.746	3584
1.75	"	39.20	84.20	1.871	3290
2	"	45.00	90.00	2.000	3114
2.25	"	50.40	95.40	2.120	2935
2.50	"	56.00	101.00	2.244	2725
2.75	"	61.33	106.33	2.363	2620
3	2239	67.20	112.20	2.484	2486
4	2238	89.20	134.20	2 982	2083
5	2237	112.00	157.00	3.444	1800
6	2233	134.40	179.40	3.986	1568
7	2232	156.80	201.80	4.844	1367
8	"	179.20	224.20	4.982	1235
9	2231	201.60	246.60	5.480	1125
10	2229	224.00	269.00	5.977	1030

* Near enough for practice, actually 2239.888.

Pressure on the plane = weight × nat cos of angle of plane.

purposes the force required to draw loaded vehicles over inclined roads. The first column expresses the rate of inclination; the second, the pressure on the plane in pounds per ton; the third, the tendency down the plane (or force required to overcome the effect of gravity) in pounds per ton; the fourth, the force required to haul one ton up the incline; the fifth, the length of level road which would be equivalent to a mile in length of the inclined road—that is, the length which would require the same motive power to be expended in drawing the load over it as would be necessary to draw it over a mile of the inclined road; the sixth, the maximum load which an average horse weighing 1200 pounds can draw over such inclines, the friction of the surface being taken at $\frac{1}{75}$ of the load drawn.

543. Character of Vehicles.—The character of the vehicles used upon a roadway has a great influence upon its endurance to the beat of the wheels. The great defect of our vehicles is that for a given load the tires of the wheels are too narrow. It has been proved by repeated and careful experiments that wheels with tires two and a half inches wide cause double the wear of wheels which have tires four and a half inches wide. It is true that on ill-conditioned and muddy roads a narrow wheel-tread is advantageous, for the reason that the thick mud has a less extended hold when it wraps around the felloes and spokes; but with this arrangement the interests of the roadway are sacrificed to the convenience of the individual who drives upon it.

544. The width of the surface covered by these narrow tires is not sufficient to bear the heavy load imposed upon it, and the knife-like tire cuts into it, forming and deepening ruts. The proper width of tire, or proper load upon any vehicle for a given width of tire, is a question that deserves more attention than is usually accorded to it.

545. The best width of tire measured when new is shown in Table LX.

These widths are best for easy traction and the maximum wear of the road-surface. To make the tires wider does not diminish the force required to move the load, and unnecessarily increases the dead weight of the vehicles. For carriages, coupés, and vehicles for light passenger use the tires need not exceed $2\frac{1}{2}$ inches and should never be less than 2 inches.

The width of tires should be established by law.

TABLE LX.

Load on each Wheel.	Description of Vehicles.			
	Two Wheels without Springs. Inches.	Two Wheels with Springs. Inches.	Four Wheels without Springs. Inches.	Four Wheels with Springs. Inches.
¼ ton	6	3	5	3
½ "	6	3	5	3
1 "	....	....	5	3½
1½ "	....	....	5	4
2 "	....	....	6	4½

546. The freight and market wagons of France have tires from 3 to 10 inches in width, usually from 4 to 6 inches. The four-wheeled freight-wagons have tires rarely less than 6 inches and the rear axle is about 14 inches longer than the fore, so that the rear wheels run on a line about an inch outside of the line of the fore-wheels. The varied gauge is also usually observed with cabs, hacks, and other four-wheeled vehicles.

547. In Bavaria the width of the wheel-tires is laid down by law as follows:

2-wheeled carts with 2 horses	4.133 inches
" " " 4 "	6.180 "
4-wheeled carts with 2 "	2.596 "
" " " 3 or 4 horses	4.133 "
" " " 5 to 8 "	6.180 "

Carts with more than four and wagons with more than eight horses are not allowed to use the road except under special permit from the authorities.

548. In Austria the width of tires for wagons carrying 2¼ tons tons is 4.33 inches, and for wagons carrying 4½ tons 6.30 inches.

549. Size of Wheels.—The wheels of a vehicle serve a twofold purpose. In the first place, they diminish the friction on the ground by transferring it from the circumference to the nave and axle; and in the second place, they serve to raise the vehicle more easily over obstacles met with on roads.

550. The friction is diminished in the proportion of the circumference of the axle to that of the wheel; and hence the larger the wheel and the smaller the axle the less is the friction.

The mechanical advantage of the wheel in surmounting an obstacle may be computed from the principle of the lever.

Let the wheel, Fig. 41, touch the horizontal line of traction in the point A and meet a protuberance BD. Suppose the line of draught CP to be parallel to AB. Join CD and draw the perpendiculars DE and DF. We may suppose the power to be applied at E and the weight at F, and the action is then the same as the bent lever

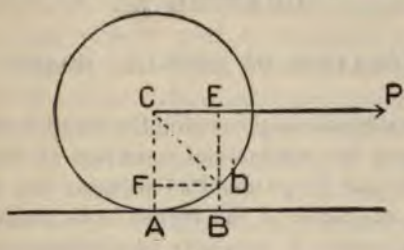


FIG. 41.

EDF turning round the fulcrum at D. Hence $P : W :: FD : DE$, but $FD : DE ::$ tan $FCD : 1$, and tan $FCD =$ tan $2(DAB)$; therefore $P = W$ tan $2(DAB)$. Now it is obvious that the angle DAB increases as the radius of the circle diminishes; and therefore, the weight W being constant, the power required to overcome an obstacle of a given height is diminished when the diameter is increased. Large wheels are therefore the best adapted for surmounting inequalities of the road.

551. There are, however, circumstances which provide limits to the height of the wheels of vehicles. If the radius AC exceeds the height of that part of the horse to which the traces are attached, the line of traction CP will be inclined to the horse, and part of the power will be exerted in pressing the wheel against the ground. The best average size of wheels is considered to be about 6 feet in diameter.

552. Wheels of large diameter do less damage to a road than small ones, and cause less draught for the horses.

553. With the same load a two-wheeled cart does far more damage than one with four wheels, and this because of their sudden and irregular twisting motion in the trackway.

554. Springs materially decrease the resistance and act preservingly on both road and vehicle.

CHAPTER XI.

LOCATION OF COUNTRY ROADS.

555. THE considerations governing the location of country roads are dependent upon the commercial condition of the country to be traversed. In old and long-inhabited sections the controlling element will be the character of the traffic to be accommodated. In such a section, the route is generally predetermined, and therefore there is less liberty of a choice and selection than in a new and sparsely settled district, where the object is to establish the easiest, shortest, and most economical line of intercommunication according to the physical character of the ground.

556. Whichever of these two cases may have to be dealt with, the same principle governs the engineer, namely, to so lay out the road as to effect the conveyance of the traffic with the least expenditure of motive power consistent with economy of construction and maintenance.

557. Economy of motive power is promoted by easy grades, by the avoidance of all unnecessary ascents and descents, and by a direct line; but directness must be sacrificed to secure easy grades and to avoid expensive construction.

558. Reconnoissance.—The selection of the best route demands much care and consideration on the part of the engineer. To obtain the requisite data upon which to form his judgment he must make a personal reconnoissance of the district. This requires that the proposed route be either ridden or walked over and a careful examination made of the principal physical contours and natural features of the district. The amount of care demanded and the difficulties attending the operations will altogether depend upon the character of the country.

559. The immediate object of the reconnoissance is to select one or more trial lines, from which the final route may be ultimately determined.

When there are no maps of the section traversed, or when those which can be procured are indefinite or inaccurate, the work of reconnoitring will be much increased.

560. In making a reconnoissance there are several points which, if carefully attended to, will very considerably lessen the labor and time otherwise required. Lines which would run along the immediate bank of a large stream must of necessity intersect all the tributaries confluent on that bank, thereby demanding a corresponding number of bridges. Those, again, which are situated along the slopes of hills are more liable in rainy weather to suffer from washing away of the earthwork and sliding of the embankments; the others which are placed in valleys or elevated plateaux, when the line crosses the ridges dividing the principal water-courses will have steep ascents and descents.

561. In making an examination of a tract of country, the first point to attract notice is the unevenness or undulations of its surface, which appears to be entirely without system, order, or arrangement; but upon closer examination it will be perceived that one general principle of configuration obtains even in the most irregular countries. The country is intersected in various directions by main water-courses or rivers, which increase in size as they approach the point of their discharge. Towards these main rivers lesser rivers approach on both sides, running right and left through the country, and into these, again, enter still smaller streams and brooks. The streams thus divide the hills into branches or spurs having approximately the same direction as themselves, and the ground falls in every direction from the main chain of hills towards the water-courses, forming ridges more or less elevated.

562. The main ridge is cut down at the heads of the streams into depressions called gaps or passes; the more elevated points are called peaks. The water which has fallen upon these peaks is the origin of the streams which have hollowed out the valleys. Furthermore, the ground falls in every direction towards the natural water-courses, forming ridges more or less elevated running between them and separating from each other the districts drained by the streams.

563. The natural water-courses mark not only the lowest lines, but the lines of the greatest longitudinal slope in the valleys through which they flow.

564. The direction and position of the principal streams give

also the direction and approximate position of the high ground or ridges which lie between them.

565. The position of the tributaries to the larger stream generally indicates the points of greatest depression in the summits of the ridges, and therefore the points at which lateral communication across the high ground separating contiguous valleys can be most readily made.

566. The instruments employed in reconnoitring, are:—The compass, for ascertaining the direction; the aneroid barometer, to fix the approximate elevation of summits, etc.; and the hand-level, to ascertain the elevation of neighboring points. If a vehicle can be used, an odometer may be added, but distances can usually be guessed or ascertained by time estimates or otherwise, closely enough for preliminary purposes. More outfit than the above (the use of which is supposed to be understood), with the best maps obtainable and a succession of travelling companions who possess a local knowledge of the country, will not be particularly useful.

567. The reconnoissance being completed, instrumental surveys of the routes deemed most advantageous should be made. When the several lines are plotted to the same scale, a good map can be prepared from which the exact location of the road can be determined.

568. In making the preliminary surveys the topographical features should be noted for a convenient distance to the right and left of the line, and all prominent points located by compass-bearings. The following data should be also obtained: the importance, magnitude, and direction of all streams and roads crossed; the character of the material to be excavated or available for embankments, the position of quarries and gravel-pits, and the modes of access thereto; and all other information that may effect a selection.

569. Topography.—There are various methods of delineating upon paper the irregularities of the surface of the ground. The method of most utility to the engineer is that by means of "contour lines." These are fine lines traced through the points of equal level over the surface surveyed, and denote that the level of the ground throughout the whole of their course is identical; that is to say, that every part of the ground over which the line passes is at a certain

height above a known fixed point termed the datum, this height being indicated by the figures written against the line.

The intervals between the lines vertically is equal and may be 1, 3, 5, 10, or more feet apart; 5 feet will be found the most useful.

The rate of inclination of the ground may be estimated by the relative proximity or distance apart of the lines. Where the ground is comparatively level they are far apart; where the surface is very hilly they lie close together.

These lines by their greater or less distance apart have the effect of shading, and make apparent to the eye the undulations and irregularities in the surface of the country.

Fig. 42 shows an imaginary tract of country the physical features of which are shown by contour lines.

570. Map.—The map should show the lengths and direction of the different portions of the line, the topography, rivers, water-courses, roads, railroads, and other matters of interest, such as town and county lines, dividing lines between property, timbered and cultivated lands, etc.

Any convenient scale may be adopted; 400 feet to an inch will be found the most useful.

Fig. 43 shows a map of this kind.

571. Memoir.—The descriptive memoir should give with minuteness all information such as the nature of the soil, character of the several excavations whether earth or rock, and such particular features as cannot clearly be shown on the map or profile.

Special information should be given concerning the rivers crossed, as to their width, depth at highest known flood, velocity of current, character of banks and bottom, and the angle of skew which the course makes with the line of the road.

572. Levels.—Levels should be taken along the course of each line, usually at every 100 feet, or at closer intervals depending upon the nature of the country.

In taking the levels, the heights of all existing roads, railroads, rivers, or canals should be noted. "Bench-marks" should be established at least every half-mile that is, marks made on any fixed object such as a gate-post, side of a house, or, in the absence of these, a cut made on a large tree. The height and exact description of each bench-mark should be recorded in the level book.

573. Cross-levels.—Wherever considered necessary levels at

Fig42.

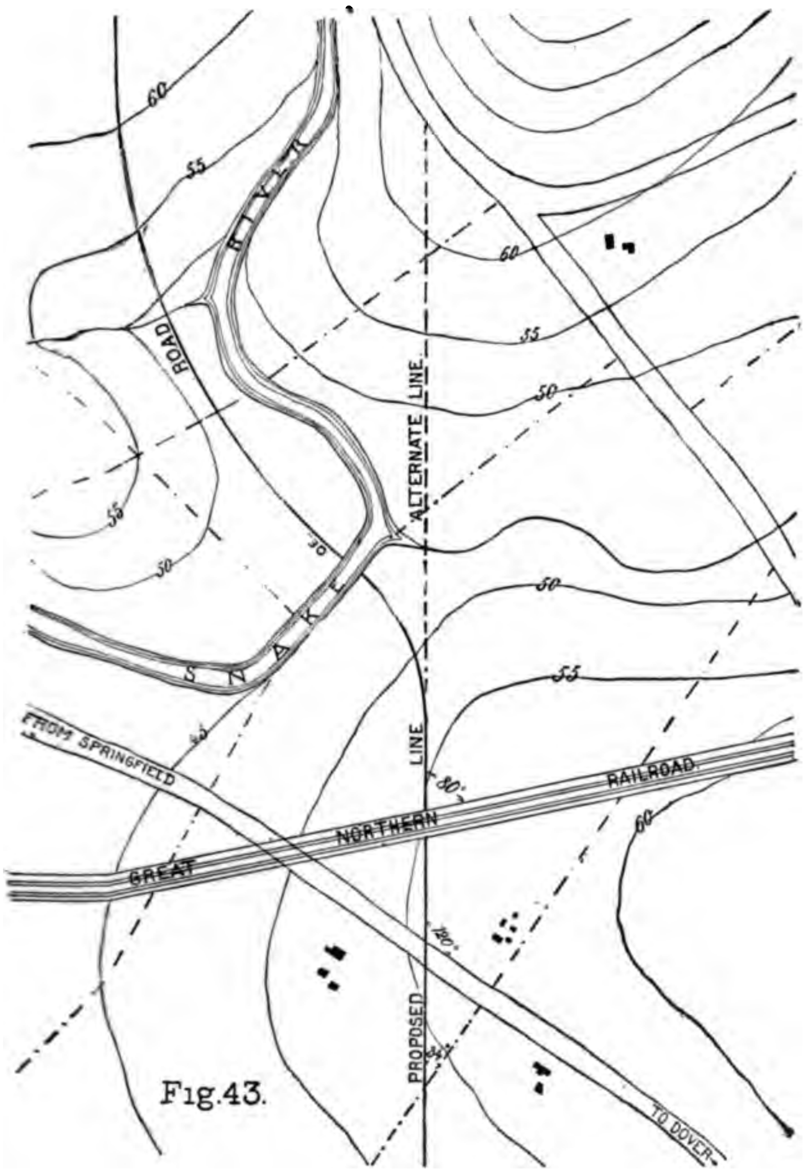

RIVER
ROAD
SNAKE
ALTERNATE LINE
PROPOSED LINE
FROM SPRINGFIELD
GREAT NORTHERN RAILROAD
TO DOVER
60
55
50
45
80°
120°

Fig. 43.

Fig. 44. PRELIMINARY PROFILE.

right angles to the centre line should be taken. These will be found useful in showing what effect a deviation to the right or left of the surveyed line would have. Cross-levels should be taken at the intersection of all roads and railroads to show to what extent, if any, these levels will have to be altered to suit the levels of the proposed road.

574. Profile.—A profile is a longitudinal section of the route, made from the levels. Its horizontal scale should be the same as that of the map; the vertical scale should be such as will show with distinctness the inequalities of the ground.

Fig. 44 shows the manner in which a profile is drawn and the nature of the information to be given upon it.

575. Bridge Sites.—The question of choosing the site of bridges is an important one. If the selection is not restricted to a particular point, the river should be examined for a considerable distance above and below what would be the most convenient point for crossing; and if a better site is found, the line of the road must be made subordinate to it. If several practicable crossings exist, they must be carefully compared in order to select the one most advantageous. The following are controlling conditions: (1) Good character of the river-bed, affording a firm foundation. If rock is present near the surface of the river-bed, the foundation will be easy of execution and stability and economy will be insured.

(2) Stability of the river-banks, thus securing a permanent concentration of the waters in the same bed. (3) The axis of the bridge should be at right angles to the direction of the current. (4) Bends in the river are not suitable localities and should be avoided if possible. A straight reach above the bridge should be secured if possible.

576. Principles to be observed in making the Final Selection. In making the final selection the following principles should be observed as far as practicable.

(*a*) To follow that route which affords the easiest grades. The easiest grade for a given road will depend upon the kind of covering adopted for its surface

(*b*) To connect the places by the shortest and most direct route commensurate with easy grades.

(*c*) To avoid all unnecessary ascents and descents. When a road is encumbered with useless ascents, the wasteful expenditure of power is considerable.

(*d*) To give the centre line such a position, with reference to the natural surface of the ground, that the cost of construction shall be reduced to the smallest possible amount.

(*e*) To cross all obstacles (where structures are necessary) as nearly as possible at right angles. The cost of skew structures increases nearly as the square of the secant of the obliquity.

(*f*) To cross ridges through the lowest pass which occurs.

(*g*) To cross either under or over railroads; for grade crossings mean danger to every user of the highway. Guards and gates frequently fail to afford protection, and the daily press is filled with accounts of accidents more or less serious; and while statistics fail to give total casualties, the aggregate must be great.

577. Examples of Cases to be Treated.—In laying out the line of a road, there are three cases which may have to be treated, and each of these is exemplified in the contour map Fig. 42, page 278. First, the two places to be connected, as the towns A and B on the plan, may be both situated in the same valley, and upon the same side of it; that is, they are not separated from each other by the main stream which drains the valley. This is the simplest case. Secondly, although both in the same valley, the two places may be on opposite sides of the valley, as at A and C, being separated by the main river. Thirdly, they may be situated in different valleys, sep-

arated by an intervening ridge of ground more or less elevated, as at A and D. In laying out an extensive line of road, it frequently happens that all these cases have to be dealt with; frequently, perhaps, during its course.

The most perfect road is that of which the course is perfectly straight and the surface practically level; and, all other things being the same, that is the best road which answers nearest to this description.

Now in the first case, that of the two towns situated on the same side of the main valley, there are two methods which may be pursued in forming a communication between them. A road following the direct line between them, shown by the thick dotted line *AB*, may be made, or a line may be adopted which will gradually and equally incline from one town to the other, supposing them to be at different levels, or which should keep, if they are on the same level, at that level throughout its entire course, following all the sinuosities and curves which the irregular formation of the country may render necessary for the fulfilment of these conditions. According to the first method, a level or uniformly inclined road might be made from one to the other; this line would cross all the valleys and streams which run down to the main river, thus necessitating deep cuttings, heavy embankments, and numerous bridges; or these expensive works might be avoided by following the sinuosities of the valley. When the sides of the main valley are pierced by numerous ravines with projecting spurs and ridges intervening, instead of following the sinuosities, it will be found better to make a nearly straight line cutting through the projecting points in such a way that the material excavated should be just sufficient to fill the hollows.

Now, of all these, the best is the straight and uniformly inclined, or the level road, although at the same time it is the most expensive. If the importance of the traffic passing between the places is not sufficient to warrant so great an outlay, it will become a matter of consideration whether the course of the road should be kept straight, its surface being made to undulate with the natural face of the country; or whether, a level or equally inclined line being adopted, the course of the road should be made to deviate from the direct line and follow the winding course which such condition is supposed to necessitate.

In the second case, that of two places situated on opposite sides of the same valley, there is, in like manner, the choice of a perfectly straight line to connect them, which would probably require a high embankment if the road was kept level, or steep inclines if it followed the surface of the country; or by winding the road, it may be carried across the valley at a higher point, where, if the level road be taken, the embankment would not be so high, or, if kept on the surface, the inclination would be reduced.

In the third case, there is, in like manner, the alternative of carrying the road across the intervening ridge in a perfectly straight line, or of deviating it to the right and left, and crossing the ridge at a point where the elevation is less.

The proper determination of the question which of these courses is the best under certain circumstances involves a consideration of the comparative advantages and disadvantages of inclines and curves. What additional increase in the length of a road would be equivalent to a given inclined plane upon it; or, conversely, what inclination might be given to a road as an equivalent to a given decrease in its length? To satisfy this question it is requisite to know the comparative force required to draw different vehicles with given loads upon level and upon variously inclined roads—a subject which is treated in Chapter X.

The route which will give the most general satisfaction consists in following the valleys as much as possible and rising afterward by gentle grades. This course traverses the cultivated lands, regions studded with farm-houses and factories. The value of such a line is much more considerable than that of a route by the ridges. The water-courses which flow down to the main valley are, it is true, crossed where they are the largest, and require works of large dimensions, but also they are fewer in number.

578. Intermediate Towns.—Suppose that it is desired to form a road between two distant towns, A and B, Fig. 45, and let us for the present neglect altogether the consideration of the physical features of the intervening country, assuming that it is equally favorable whatever line we select. Now at first sight, it would appear that under such circumstances a perfectly straight line drawn from one town to the other would be the best that could be chosen. On more careful examination, however, of the locality, we may find that there is a third town, C, situated somewhat on one side of the

straight line which we have drawn from A to B; and although our primary object is to connect only the two latter, that it would nevertheless be of considerable service if the whole of the three

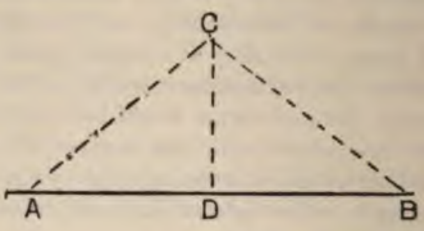


FIG. 45.

towns were put into mutual connection with each other. Now this may be effected in three different ways, any one of which might, under the circumstances, be the best. In the first place, we might, as originally suggested, form a straight road from A to B, and in a similar manner two other straight roads from A to C, and from B to C, and this would be the most perfect way of effecting the object in view, the distance between any two of the towns being reduced to the least possible. It would, however, be attended with considerable expense, and it would be requisite to construct a much greater length of road than according to the second plan, which would be to form, as before, a straight road from A to B, and from C to construct a road which should join the former at a point D, so as to be perpendicular to it. The traffic between A or B and C would proceed to the point D and then turn off to C. With this arrangement, while the length of the roads would be very materially decreased, only a slight increase would be occasioned in the distance between C and the other two towns. The third method would be to form only the roads AC and CB, in which case the distance between A and B would be somewhat increased, while that between AC or B and C would be diminished, and the total length of road to be constructed would also be lessened.

As a general rule it may be taken that the last of these methods is the best and most convenient for the public; that is to say, that if the physical character of the country does not determine the course of the road, it will generally be found best not to adopt a

perfectly straight line, but to vary the line so as to pass through all the principal towns near its general course.

579. Mountain Roads.—The location of roads in mountainous countries presents greater difficulties than in an ordinary undulating country; the same latitude in adopting undulating grades and choice of position is not permissible, for the maximum gradient must be kept before the eye perpetually. A mountain road has to be constructed on the maximum grade or at grades closely approximating it, and but one fixed point can be obtained before commencing the survey, and that is the lowest pass in the mountain range; from this point the survey must be commenced. The reason for this is that the lower slopes of the mountains are flatter than those at their summit; they cover a larger area and merge into the valley in diverse undulations. So that a road at a foot of a mountain may be carried at will in the desired direction by more than one route, while at the top of a mountain range any deviation from the lowest pass involves increased length of line. The engineer having less command of the ground, owing to the reduced area he has to deal with and the greater abruptness of the slopes, is liable to be frustrated in his attempt to get his line carried in the direction he wishes it to follow.

580. It is a common practice to run a mountain survey up-hill, but such practice should be avoided. Wherever an acute-angled zigzag is met with on a mountain road near the summit, the inference to be drawn is that the line being carried up-hill on reaching the summit was too low and the zigzag was necessary to reach the desired pass. The only remedy in such a case is by a resurvey beginning at the summit and running down-hill. This method requires a reversal of the usual one. The grade line is first staked out and its horizontal location surveyed afterwards. The most appropriate instrument for this work is a transit with a vertical circle on which the telescope may be set to the angle of the maximum grade.

581. Loss of Height.—Loss of height is to be carefully avoided in a mountain road. By loss of height is meant an intermediate rise in a descending grade. If a descending grade is interrupted by the introduction of an unnecessary ascent, the length of the road will be increased over that due to the continuous grade by the length of the portion of the road intervening between the summit

of the rise and the point in the road in a level with that rise—a length which is double that due on the gradient to the height of the rise. For example, if a road descending a mountain rises at some intermediate point to cross over a ridge or spur, and the height ascended amounts to 110 feet before the descent is continued, such a road would be just one mile longer than if the descent had been uninterrupted; for 110 feet is the rise due to a half-mile length at 1:24.

582. Water on Mountain Roads.—Water is needed by the workmen and during the construction of the road; it is also very necessary for the traffic, especially during hot weather; and if the road exceeds 5 miles in length provision should be made to have it either close to or within easy reach of the road. With a little ingenuity the water from springs above the road, if such exist, can be led down to drinking-fountains for men, and to troughs for animals.

In a tropical country it would be a matter for serious consideration if the best line for a mountain road 10 miles in length or upwards, but without water, should not be abandoned in favor of a worse line with a water-supply available.

583. Halting-places.—On long lines of mountain roads halting-places should be provided at convenient intervals.

584. Alignment.—No hard and fast rule can be laid down for the alignment of a road; it will depend both upon the character of the traffic on it and upon the "lay of the land." To promote economy of transportation it should be straight; but if straightness is obtained at the expense of easy grades that might have been obtained by deflections and increase of length, it will prove very expensive to the community that uses it.

585. Where curves are necessary, employ the greatest radius possible and never less than fifty feet. They may be circular or parabolic. The parabolic will be found exceedingly useful for joining tangents of unequal length, and for following contour lines; its curvature being least at its beginning and ending, makes the deviations from a straight line less strongly marked than by a circular arc (see Figs. 46 to 49).

586. When a curve occurs on an ascent, the grade at that place must be diminished in order to compensate for the additional resistance of the curve.

TYPES OF CURVES.

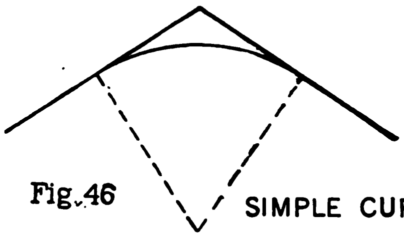


Fig. 46 SIMPLE CURVE

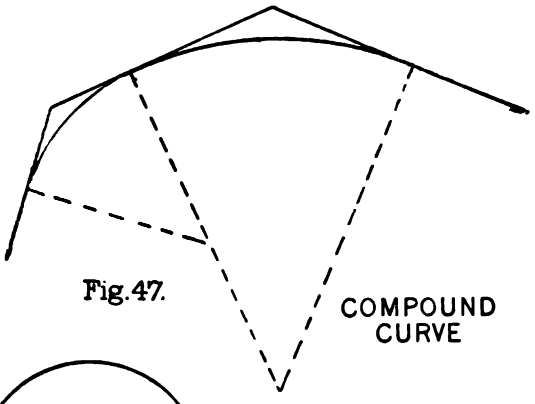


Fig. 47. COMPOUND CURVE

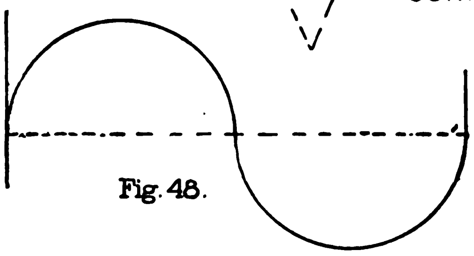


Fig. 48. REVERSE CURVE

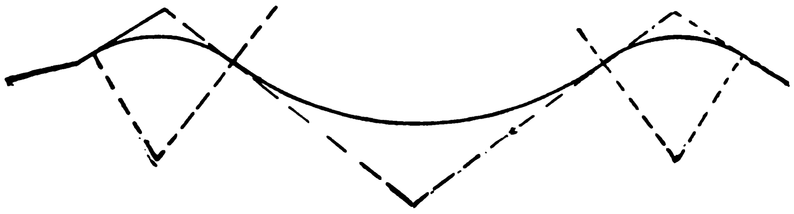


FIG. 49.
DOUBLE-REVERSE CURVE

587. The width of the wheelway on curves must be increased. This increase should be one quarter of the width for central angles between 90 and 120 degrees, and one half for angles between 60 and 90 degrees.

588. Excessive crookedness of alignment is to be avoided, for any unnecessary length causes a constant threefold waste: first, of the interest of the capital expended in making that unnecessary portion; secondly, of the ever-recurring expense of repairing it; and thirdly, of the time and labor employed in travelling over it.

589. The curving road around a hill may be often no longer than the straight one over it, for the latter is straight only with reference to the horizontal plane, while it is curved as to the vertical plane; the former is curved as to the horizonal plane, but straight as to the vertical plane. Both lines curve, and we call the one passing over the hill straight only because its vertical curvature is less apparent to our eyes.

590. The difference in length between a straight road and one which is slightly curved is very small. If a road between two places ten miles apart were made to curve so that the eye could nowhere see farther than one quarter of a mile of it at once, its length would exceed that of a straight road between the same points by only about four hundred and fifty feet.

591. Zigzags.—The method of surmounting a height by a series of zigzags, or by a series of reaches with practicable curves at the turns, is objectionable.

(1) An acute-angled zigzag obliges the traffic to reverse its direction without affording it convenient room for the purpose. The consequence is that with slow traffic a single train of vehicles is brought to a stand, while if two trains of vehicles travelling in opposite directions meet at a zigzag a block ensues.

(2) With zigzags little progress is made towards the ultimate destination of the road; height is surmounted, but horizontal distance is increased for which there is no necessity or compensation.

(3) Zigzags are dangerous. In case of a runaway down-hill the zigzag must prove fatal.

(4) If the drainage cannot be carried clear of the road at the end of each reach, it must be carried under the road in one reach only to appear again at the next, when a second bridge, culvert, or drain will be required, and so on at the other reaches. If the

drainage can be carried clear at the termination of each reach, the lengths between the curves will be very short, entailing numerous zigzag curves, which are expensive to construct and maintain.

592. Final Location.—The route being finally determined upon, it requires to be located. This consists in tracing the line, placing a stake at every 100 feet on the straight portions and at every 50 or 25 feet on curves. At the tangent points of curves, and at points of compound and reverse curves, a larger and more permanent stake should be placed. Lest those stakes should be disturbed in the process of construction, their exact distance from several points outside of the ground to be occupied by the road should be carefully measured and recorded in the note-book, that they may be replaced. The stakes above referred to show the position of the centre line of the road, and form the base line from which all operations of construction are carried on. Levels are taken at each stake, and cross-levels are taken at every change of longitudinal slope.

593. Construction Profile.—The construction or working profile is made from the levels obtained on location. It should be drawn to a horizontal scale of 400 feet to the inch and a vertical scale of 20 feet to the inch. Fig. 50 represents a portion of such a profile. The figures in column A represent the elevation of the ground at every 100 feet, or where a stake has been driven, above datum. The figures in column B are the elevations of the grade above datum. The figures in column C indicate the depth of cutting or height of fill; they are obtained by taking the difference between the level of the surface of the ground and the level of the road. The two straight parallel lines represent the grade of the road; the upper line is intended to show the upper surface of the road when finished, while the lower line represents what is termed the subgrade or formation level. All the dimensions refer to the formation level, to which the surface of the ground is to be formed to receive the road-covering.

At all changes in the rate of inclination of the grade line a heavier vertical line should be drawn.

594. Gradient.—The grade of a line is its longitudinal slope, and is designated by the proportion between its length and the difference of height of its two extremes. The ratio of these two quantities gives it its name: if the road ascends or falls one foot in every twenty feet of its length, it is said to have a grade of 1 : 20

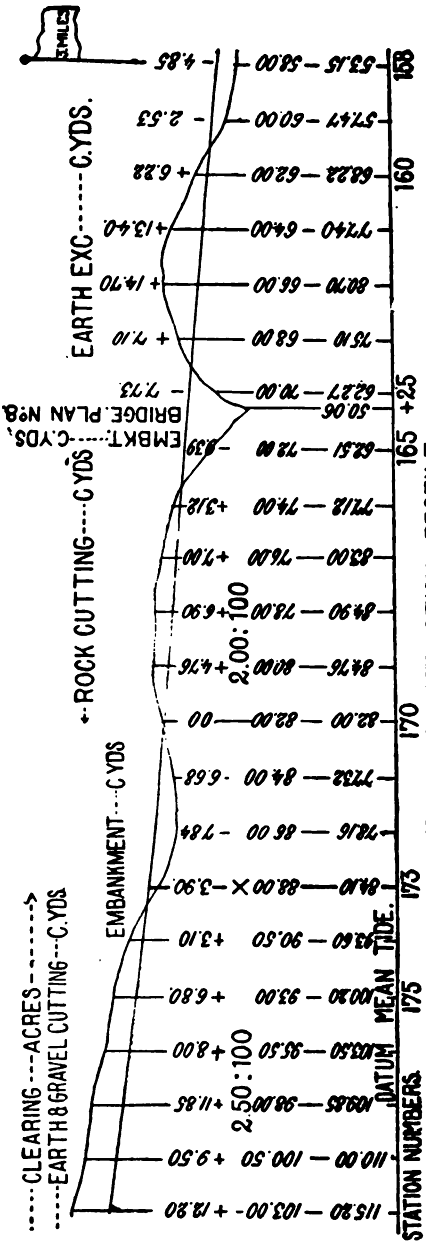


Fig. 50. CONSTRUCTION PROFILE.

or a 5 per cent grade. Grades are of two kinds, maximum and minimum. The maximum is the steepest which is to be permitted and which on no account is to be exceeded. The minimum is the least allowable for good drainage. (For method of designating grades see Table LXIII.)

595. Determination of Gradients.—The maximum grade is fixed by two considerations, one relating to the power expended in ascending, the other to the acceleration in descending the incline.

There is a certain inclination, depending upon the degree of perfection given to the surface of the road, which cannot be exceeded without a direct loss of tractive power. This inclination is that in descending which, at a uniform speed, the traces slacken, or which causes the vehicles to press on the horses; the limiting inclination within which this effect does not take place is the angle of repose.

596. The angle of repose for any given road-surface can be easily ascertained from the tractive force required upon a level with the same character of surface. Thus if the force necessary on a level to overcome the resistance of the load is $\frac{1}{40}$ of its weight, then the same fraction expresses the angle of repose for that surface.

597. On all inclines less steep than the angle of repose a certain amount of tractive force is necessary in the descent as well as in the ascent, and the mean of the two drawing forces, ascending and descending, is equal to the force along a level road. Thus on such inclines as much mechanical force is gained in the descent as is lost in the ascent. From this it might be inferred that when a vehicle passes alternately each way along the road, no real loss is occasioned by the inclination of the road; such is not, however, practically the fact with animal power, for whilst it is necessary in the ascending journey to have either a less or a greater number of horses than would be requisite if the road were entirely level, no corresponding reduction can be made in the descending journey. On inclines which are more steep than the angle of repose, the load presses on the horses during their descent, so as to impede their action, and their power is expended in checking the descent of the load; or if this effect be prevented by the use of any form of drag or brake, then the power expended on such drag or brake corresponds to an equal quantity of mechanical power expended in the ascent, for which no equivalent is obtained in the descent.

598. Men and all animals can ascend steeper slopes than they can descend. A man walks slowly up-hill and quickly down-hill. A horse does the reverse: the steeper the ascent the faster, until fatigued, he attempts to travel, while in descending he moves at a slow trot which gradually subsides into a walk. Consequently the inclination which admits of high speed in descending practically controls the maximum grade.

599. The maximum grade for a given road will depend (1) upon the class of traffic that will use it, whether fast and light, slow and heavy, or mixed, consisting of both light and heavy; (2) upon the character of the pavement adopted; and (3) upon the question of cost of construction. Economy of motive power and low cost of construction are antagonistic to each other, and the engineer will have to weigh the two in the balance.

600. It is evident, therefore, that no fixed maximum gradient can be adopted in all situations.

For fast and light traffic the grades should not exceed 2 per cent; for mixed traffic 3 per cent may be adopted; while for slow traffic combined with economy 5 per cent should not be exceeded. This grade is practicable but not convenient.

601. The maximum grade for various paving materials is as follows:

Stone blocks	all grades
Wood	5 per cent
Asphalt	$2\frac{1}{2}$ "
Brick	5 "
Broken stone	3 "

602. The maximum grade adopted by the French engineers for macadamized roads is 5 per cent or 1 : 20. The maximum adopted by Telford was 1 : 30.

603. It is obvious from Table LVIII that the smoother the road-surface the easier must be the grade. From this fact it has been deduced that on rough-surfaced roads steeper grades are permissible than on smooth roads. This deduction is misleading. The force of gravity which has to be overcome is the same whether the road-surface be rough or smooth. The rough surface affords better foothold for the horse than the smooth surface, and thus assists him to exert his utmost force, but the great friction produced between the wheels and the rough surface requires the expenditure

of greater tractive force than would be required on a smooth surface. In practice there is no pavement which combines the opposite requirements of an even smooth surface for the wheels and a sufficiently rough surface affording good foothold for the horses, and a compromise of advantages must therefore be made in most cases. Where the extent and importance of the traffic will warrant the expense, stone trackways afford an excellent method for overcoming the disadvantage of smooth pavements on inclines.

604. To Determine the Maximum Grade.—Let L denote the gross load to be hauled up an incline; f, the proportion of the resistance to the load on a level; S, the sine of the angle of the incline. Then $(f+S) \,.\, L$ is the greatest resistance to be overcome in ascending the incline; and this should not exceed the greatest tractive force which the horse is capable of exerting. Let P be that force; then $(f+S) \,.\, L$ should not be greater than P, or S should not be greater than $\frac{P}{L} - f$. This condition is essential and fixes the maximum grade.

To avoid excessive acceleration of speed in descending S should not exceed f.

The proportion of the resistance f differs, as shown in Table LXI very much for different sorts of road coverings. It consists of two parts, one arising from friction and another arising from vibration, and increases with the velocity of transit.

TABLE LXI.

VALUE OF f.

Stone pavement	$0.015 = \frac{1}{67}$
Broken stone	$0.020 = \frac{1}{49}$
Gravel road	$0.067 = \frac{1}{15}$
Soft sand and loose gravel	$0.143 = \frac{1}{7}$

605. Grade of Mountain Roads.—Although mountain roads are in general projected for slow traffic, yet as civilization and wealth in a country increase, roads adapted to the use of wheeled vehicles gradually become used by an increasing amount of quick traffic. Ascending grades of 1:20, 1:18, 1:16 are too steep to permit of carriages drawn by horses ascending for any distance except at a foot-pace. Hack conveyances with relays at short distances can and do pro-

ceed more rapidly over hill roads with these grades, but such service is accompanied with a great amount of cruelty to the draught animals. Private horses are not called upon to work like hired hackneys, which are supposed to be able to do double the work they were capable of in their younger, and better, days; therefore, continuous grades of 1 : 16, 1 : 18, 1 : 20 means, as respects private quick traffic, its conversion into slow traffic. On the descent of such inclinations horses can only travel with safety at a slow trot, which probably subsides into a walk at the turns and when meeting other traffic. To ride down a slope of 5 per cent for a long distance is disagreeable.

With a gradient of 4 per cent on a mountain road the slow traffic would be so well suited that ten miles continuous ascent could be surmounted without a halt or undue exertion on the part of the draught animals. Such a grade would not reduce quick traffic to a walk throughout an ascent, and it would permit of horses descending with safety at six to eight miles an hour.

606. Minimum Grade.—From the previous considerations it would appear that an absolutely level road was the one to be sought for, but this is not so; there is a minimum or least allowable grade which the road must not fall short of, as well as a maximum one which it must not exceed. If the road was perfectly level in its longitudinal direction, its surface could not be kept free from water without giving it so great a rise in its middle as would expose vehicles to the danger of overturning.

The minimum grade established in France by the Corps des Ponts et Chaussées is .008, or 1 in 125; this may be adopted as the minimum, and in a perfectly level country the road should be artificially formed into gentle undulations approximating this minimum limit.

607. Undulating Grades.—From the fact that the power required to move a load at a given velocity on a level road is decreased on a descending grade to the same extent that it is increased in ascending the same grade, it must not be inferred that the animal force expended in passing alternately each way over a rising and falling road will gain as much in descending the several inclines as it will lose in ascending them. Such is not the case. The animal force must be sufficient, either in power or number, to draw the load over the level portions and up the steepest inclines

of the road, and in practice no reduction in the number of horses can be made to correspond with the decreased power required in descending the inclines.

The popular theory that a gentle undulating road is less fatigu-

EXAMPLES OF THE APPLICATION OF VERTICAL CURVES.

Fig. 51.

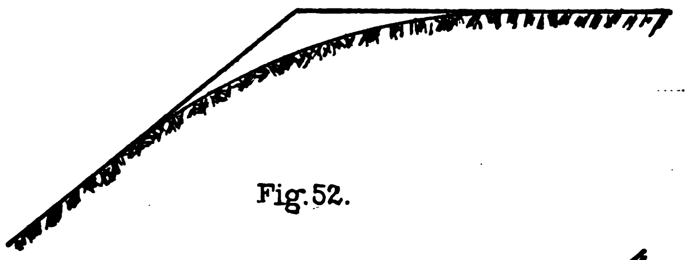


Fig. 52.

Fig. 53

ing to horses than one which is perfectly level is erroneous. The assertion that the alternations of ascent, descent, and levels call into play different muscles, allowing some to rest while others are exerted, and thus relieving each in turn, is demonstrably false, and

contradicted by the anatomical structure of the horse. Since this doctrine is a mere popular error, it should be utterly rejected, not only because false in itself, but still more because it encourages the building of undulating roads, and this increases the labor and cost of transportation upon them.

608. Level Stretches.—On long ascents it is generally recommended to introduce level or nearly level stretches at frequent intervals in order to rest the animals. These are objectionable when they cause loss of height, and animals will be more rested by halting and unharnessing for half an hour than by travelling over a level portion. The only case which justifies the introduction of levels into an ascending road is where such levels will advance the road towards its objective point; where this is the case there will be no loss of either length or height, and it will simply be exchanging a level road below for a level road above.

TABLE LXII.

DIFFERENT METHODS OF DESIGNATING THE SAME GRADES.

American Method. Feet per 100 feet.	English Method.	Feet per Mile.	Angle with the Horizon.
¼	1 : 400	13.2	0° 8′ 36″
½	1 : 200	26.4	0 17 11
¾	1 : 150	39.6	0 22 55
1	1 : 100	52.8	0 34 23
1¼	1 : 80	66	0 42 58
1½	1 : 66⅔	79.2	0 51 28
1¾	1 : 57⅐	92.4	1 0 51
2	1 : 50	105.6	1 8 6
2¼	1 : 44⅘	118.8	1 17 39
2½	1 : 40	132	1 25 57
2¾	1 : 36⅓	145.2	1 34 22
3	1 : 33⅓	158.4	1 43 08
3¼	1 : 30⅘	171.6	1 51 42
3½	1 : 28⅐	184.8	2 0 16
3¾	1 : 26⅔	198	2 8 51
4	1 : 25	211.2	2 17 26
4¼	1 : 23⅓	224.4	2 26 10
4½	1 : 22⅙	237.6	2 34 36
4¾	1 : 21	250.8	2 43 35
5	1 : 20	264	2 51 44
6	1 : 13⅔	316 8	3 26 12
7	1 : 14⅔	369.6	4 0 15
8	1 : 12½	422.4	4 34 26
9	1 : 11⅑	475.2	5 8 31
10	1 : 10	528.	5 42 37

609. Establishing the Grade.—When the profile of a proposed route has been made, a grade line is drawn upon it (usually in red) in such a manner as to follow its general slope, but to average its irregular elevation and depressions.

If the ratio between the whole distance and the height of the line is less than the maximum grade intended to be used, this line will be satisfactory; but if it be found steeper, the cuttings or the length of the line will have to be increased: the later is generally preferable.

610. The apex or meeting point of all curves should be rounded off by a vertical curve shown in Figs. 51 to 53.

CHAPTER XII.

WIDTH AND TRANSVERSE CONTOUR.

611. A road should be wide enough to accommodate the traffic for which it is intended, and should comprise a wheelway for vehicles and a space on each side for pedestrians.

612. The wheelway of country highways need be no wider than is absolutely necessary to accommodate the traffic using it; in many places a track wide enough for a single team is all that is necessary. But the breadth of the land appropriated for highway purposes should be sufficient to provide for all future increase of traffic. The wheelways of roads in rural sections should be double; that is, one portion paved (preferably the centre) and the other left with the natural soil. The latter if kept in repair will for at least one half the year be preferred by teamsters.

613. The minimum width of the paved portion, if intended to carry two lines of travel, is fixed by the width required to allow two vehicles to pass each other safely. This width is 16 feet. If intended for a single line of travel, 8 feet is sufficient but suitable turnouts must be provided at frequent intervals. The most economical width for any roadway is some multiple of eight.

614. Wide roads are the best; they expose a larger surface to the drying action of the sun and wind, and require less supervision than narrow ones. Their first cost is greater than narrow ones, and that nearly in the ratio of the increased width.

615. The cost of maintaining a mile of road depends more upon the extent of the traffic than upon the extent of its surface, and unless extremes be taken the same quantity of material will be necessary for the repair of the road whether wide or narrow which is subjected to the same amount of traffic. The cost of spreading the materials over the wide road will be somewhat greater, but the cost of the materials will be the same. On narrow roads the traffic, being confined to one track, will wear more severely than if spread over a wider surface.

616. The width of land appropriated for road purposes varies in the United States from 49½ to 66 feet; in England and France

from 26 to 66 feet. And the width or space macadamized is also subject to variation; in the United States the average width is 16 feet; in France it varies between 16 and 22 feet; in Belgium 8¼ feet seems to be the regular width, while in Austria it varies from 14½ to 26¼ feet.

Figs. 85–92, page 342, show the subdivision of the roadway into wheelway, sidewalks, and ditches.

617. Width of Mountain Roads.—Mountain roads should be proportioned in width to the amount of traffic; they should be neither too wide nor too narrow. If of excessive width, the cost of construction is increased; if too narrow, traffic will be interrupted by blockades. An economical width is 24 feet, and the stone covering should extend from gutter to guttre. If the center only is covered, the road will soon be destroyed, as, by reason of the curves on a mountain side predominating over straight reaches, the traffic will hug either one side of the road or the other.

Table LXIII shows the number of acres required per mile for different widths of roadway.

TABLE LXIII.

ACRES REQUIRED PER MILE FOR DIFFERENT WIDTHS OF ROADWAY.

Width. Feet.	Acres per mile.	Width. Feet.	Acres per mile.	Width. Feet.	Acres per mile.	Width. Feet.	Acres per mile.	Width. Feet.	Acres per mile.
¼	.033	19	2.30	40	4.85	59	7.15	80	9.70
½	.066	20	2.42	41	4.97	60	7.27	81	9.82
1	.121	21	2.55	41¼	5.00	61	7.39	82	9.94
2	.242	22	2.67	42	5.09	62	7.52	82½	10.00
3	.364	23	2.79	43	5.21	63	7.64	83	10.06
4	.485	24	2.91	44	5.33	64	7.76	84	10.18
5	.606	24¾	3.00	45	5.45	65	7.88	85	10.30
6	.727	25	3.03	46	5.58	66	8.00	86	10.42
7	.848	26	3.15	47	5.70	67	8.12	87	10.54
8	.970	27	3.27	48	5.82	68	8.24	88	10.66
8¼	1.00	28	3.39	49	5.94	69	8.36	89	10.78
9	1.09	29	3.52	49½	6.00	70	8.48	90	10.90
10	1.21	30	3.64	50	6.06	71	8.61	90¾	11.00
11	1.33	31	3.76	51	6.18	72	8.73	91	11.03
12	1.46	32	3.88	52	6.30	73	8.85	92	11.15
13	1.58	33	4.00	53	6.42	74	8.97	93	11.27
14	1.70	34	4.12	54	6.55	74¼	9.00	94	11.39
15	1.82	35	4.24	55	6.67	75	9.09	95	11.51
16	1.94	36	4.36	56	6.79	76	9.21	96	11.63
16½	2.00	37	4.48	57	6.91	77	9.33	97	11.75
17	2.06	38	4.61	57¾	7.00	78	9.45	98	11.87
18	2.18	39	4.73	58	7.08	79	9.58	99	12.00
								100	12.12

618. Transverse Contour.—The centre of all roadways should be higher than the sides. The object of this is to facilitate the flow of the rain-water to the gutters. Where a good surface is maintained a very moderate amount of rise is sufficient for this purpose. Earth roads require the most and asphalt the least. The rise should bear a certain proportion to the width of the carriageway. The most suitable proportions for the different paving materials is shown in the following table:

TABLE LXIV.

AMOUNT OF TRANSVERSE RISE REQUIRED FOR DIFFERENT PAVEMENTS.

Kind of Surface.		Proportion of the Carriageway Width.
Earth	Rise at centre	$\frac{1}{40}$
Gravel	"	$\frac{1}{50}$
Broken stone	"	$\frac{1}{60}$
Stone blocks	"	$\frac{1}{80}$
Wood	"	$\frac{1}{100}$
Brick	"	$\frac{1}{60}$
Asphalt	"	$\frac{1}{80}$

619. Form of Transverse Contour.—All authorities agree that the form should be convex, but they differ in the amount and form of the convexity. Circular arcs, two straight lines joined by a circular arc and ellipses all have their advocates, but the best form for streets will be found to be a parabolic curve starting from the edge of the gutter next the carriageway or one foot from the curb line. Fig. 54 shows this form, which is obtained in the following manner: Divide the ordinate or the width between the edge of the gutter and the centre of the street into 10 equal parts, and raise perpendiculars the length of which will be determined by multiplying the rise at the center by the respective number of each perpendicular in the diagram. The amounts thus obtained can be added to the rod readings, and the stakes set at the proper distance across the street with their tops at this level will give the true curve.

620. For country roads a curve of suitable convexity may be obtained as follows: Give $\frac{7}{8}$ of the total rise at $\frac{1}{4}$ the width from the centre to the side, and $\frac{5}{8}$ of the total rise at $\frac{1}{2}$ the width (Fig. 55).

621. Excessive height and convexity of cross-section contract the width of the wheelway, by concentrating the traffic at the

TRANSVERSE CONTOUR OF STREETS AND ROADS.

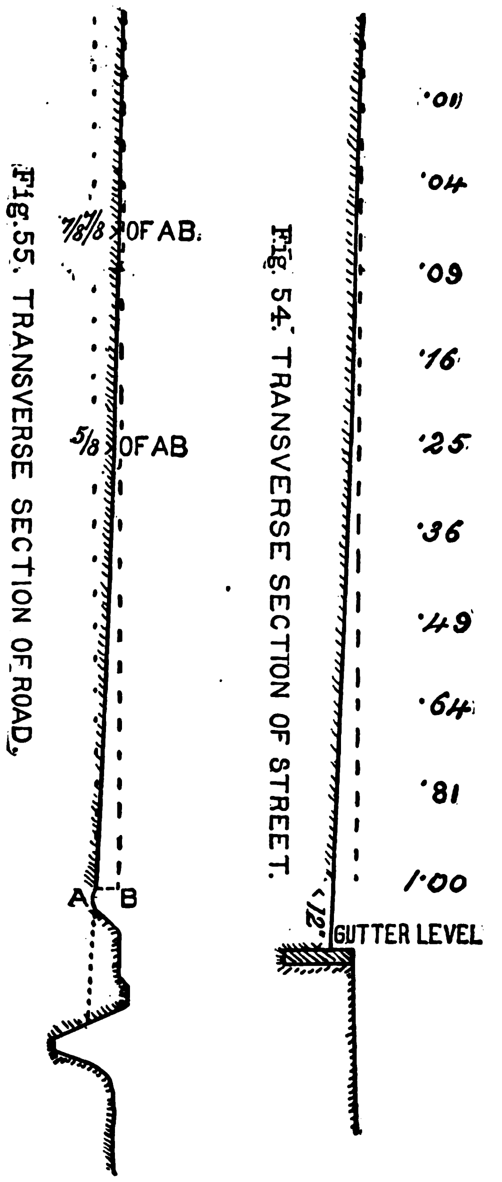


Fig. 55. TRANSVERSE SECTION OF ROAD.

Fig. 54. TRANSVERSE SECTION OF STREET.

centre, that being the only part where a vehicle can run upright. The force required to haul vehicles over such cross-sections is increased, because an undue proportion of the load is thrown upon two wheels instead of being distributed equally over the four. The continual tread of horses' feet in one track soon forms a depression which holds water, and the continuous travel of vehicles in one track soon wears ruts which retain water, and the surface is not so dry as with a flatted section, which allows the traffic to distribute itself over the whole width.

622. Sides formed of straight lines are also objectionable. They wear hollow, retain water, and defeat the object sought by raising the centre.

623. Concave Form.—In Triest, Austria, the early pavements were laid concave, i.e., inclining to the middle, along which, under the surface-canals or sewers extended with gratings at intervals for the admission of surface-drainage. The same method, but with open channels through the centre, is practised in several South American towns. Experience has proved that this plan is not desirable or convenient for traffic.

624. The required convexity should be obtained by rounding the formation surface, and not by diminishing the thickness of the covering at the sides.

625. On hillside and mountain roads it is generally recommended that the surface should consist of a single slope inclining inwards. There is no reason for or advantage gained by this method. The form best adapted to these roads is the same as for a road under ordinary conditions, viz., that described in Art. 619.

626. With a roadway raised in the centre and the rain-water draining off to gutters on each side, the drainage will be more effectual and speedy than if the drainage of the outer half of the road has to pass over the inner half. The inner half of such road is usually subjected to more traffic than the outer half. If formed of a straight incline, this side will be worn hollow and retain water. The inclined flat section never can be properly repaired to withstand the traffic. Consequently it never can be kept in good order, no matter how constantly it may be mended. It is always below par. When heavy rain falls it is seriously damaged.

CHAPTER XIII.

EARTH-WORK.

627. Earth-work.—The term "earth-work" is applied to all the operations performed in the making of the excavations and embankments to prepare them for receiving the road-covering. In its widest sense it comprehends work in rock as well as in the looser material of the earth's crust.

628. Equalizing Earth-work is a term applied to the process of so adjusting the formation or sub-grade level of an inter ·led work that the earth from the cuttings shall be as nearly as possible sufficient to make the embankments and no more. The art of making this adjustment by the eye upon a profile of the ground with sufficient accuracy is soon acquired by practice. In most cases it is essential to economy in the cost of the work. For any surplus of embankment over cutting must be made up by borrowing, and the earth from any surplus of cutting over embankment must be wasted, both of these operations involve additional cost for labor and land. But cases sometimes occur in which it is more economical to make an embankment from borrow-pits close at hand than to bring the necessary material from a far-distant cutting on the line of the works, or in which it is more economical to waste part of the material from a cutting than to send it to a far-distant embankment on the line of the works, and these points must be decided by the engineer to the best of his judgment in each particular case.

629. Transverse Balancing.—When the road lies along the side of a hill, so that it is partly in excavation and partly in embankment, it is necessary to so place its centre line that these two parts of cross-section may balance. When the ground has a uniform slope the desired end would be obtained (if the side slopes were the same for excavation and embankment and if no shrinkage existed),

by locating the centre line of the road upon the surface of the ground. In other cases, as when the side of the excavation slopes 1 to 1 and that of the embankment 2 to 1, a formula to determine the position of the centre line may be readily established.

630. If earth be wanted for a neighboring embankment, the amount of excavation may be easily increased by moving the centre of the road farther into the hill, with the additional advantage of lessening its liability to slip. The line may be thus changed on the map according to the notes of the cross-section in the level book, and be subsequently moved by a corresponding quantity on the ground.

631. When the slope of the ground is very steep the transverse balance must be disregarded and the road made chiefly in excavation, to avoid the insecurity of a high embankment.

632. Borrow-pits.—When the excavations on the line of the road do not furnish sufficient material for the embankments, the deficiency is obtained either by widening the excavations, or from an excavation termed a "borrow-pit," made in the vicinity of the embankment.

633. Spoil-banks.—If the excavations furnish more material than is required for the embankments, the excess is generally deposited in a convenient place on the land adjoining the excavation, in banks termed "spoil-banks."

Both these cases are expensive and objectionable. It is therefore very desirable to make the excavation and embankment "balance" each other. If the calculations show much disparity in the two amounts, the location of the line should be changed in some way so as to effect the desired equality.

634. The equalization must, however, be restrained within certain limits, for it should evidently be abandoned when, in order to form sufficient excavation to make the embankment, it would be necessary to go to such a distance that the cost of transport would exceed the cost of borrowing for the banks and wasting the distant excavation in spoil-banks.

635. The comparison of the price of transport with that of excavation and land will therefore determine the distance within which the balancing must be established.

636. The form to be given to the borrow-pits and spoil-banks will depend in a great degree upon the locality; they should as far as

practicable be located so that the cost of removal of the earth shall be the least possible.

637. Staking out Borrow-pits.—Borrow-pits should be staked out by the engineer and their contents calculated, unless the contractor is to be paid by embankment measurements. A number of cross-profiles are taken of the original surface, and (on the same lines) on the bottom of the pit, after it is excavated, which furnish the depth of cutting at each required point. Borrow-pits should be regularly excavated so that they may not present an unsightly appearance when abandoned.

638. Shrinkage.—The equality recommended must be taken with an important qualification, dependent upon the fact that earth transferred from excavation to embankment shrinks, or settles so as to occupy less space in the bank than it did in its natural state.

Rock, on the contrary, occupies more space when broken.

639. In estimating the relative amounts of excavation and embankment required, allowance must be made for difference in the spaces occupied by the material before excavation and after it is settled in embankment. The shrinkage of the different materials is about as follows :

Gravel	8 per cent
Gravel and sand	9 " "
Clay and clay earths	10 " "
Loam and light sandy earths	12 " "
Loose vegetable soil	15 " "
Puddled clay	25 " "

Rock, on the other hand, increases in value by being broken up, and does not settle again into less than its original bulk. The increase may be taken at fifty per cent.

Thus an excavation of loam measuring 1000 cubic yards will form only about 880 cubic yards of embankment, or an embankment of 1000 cubic yards will require about 1120 cubic yards measured in excavation to make it. A rock excavation measuring 1000 yards will make from 1500 to 1700 cubic yards of embankment, depending upon the size of the fragments.

640. The lineal settlement of earth embankments will be about in the ratio given above; therefore either the contractor should be instructed in setting his poles to guide him as to the

height of grade on an earth embankment to add the required percentage to the fill marked on the stakes, or the percentage may be included in the fill marked on the stakes. In rock embankments this is not necessary.

641. Failure of Earth-work.—The failure of earth-work is due to the slipping or sliding of its parts on each other, and its stability arises from resistance to the tendency so to slip.

In solid rock, that resistance arises from the elastic stress of the material, when subjected to a shearing force; but in the mass of earth, as commonly understood, it arises partly from the friction between the grains, and partly from their mutual adhesion; which latter force is considerable in some kinds of earth, such as clay, especially when moist.

But the adhesion of earth is gradually destroyed by the action of air and moisture, and of the changes of the weather, and especially by alternate frost and thaw; so that its friction is the only force which can be relied upon to produce permanent stability.

642. The temporary additional stability, however, which is produced by adhesion, is useful in the execution of earth-work, by enabling the sides of a cutting to stand for a time with a vertical face for a certain depth below its upper edge. That depth is greater, the greater the adhesion of the earth as compared with its heaviness; it is increased by a moderate degree of moisture, but diminished by excessive wetness.

The following are some of its values:

Earth.	Greatest depth of tem. vert. face.
Clean dry sand and gravel from	0 to 1 foot.
Moist sand and ordinary surface mould from	3 " 6 feet
Clay (ordinary) from	10 " 16 "
Compact gravel from	10 " 15 "

643. One of the effects of the temporary stability due to adhesion is seen in the figure of the surface left after a "slip" has taken place in earth-work. That surface is not a uniform slope, inclined at the angle of repose, but is concave in its vertical section, being vertical at its upper edge, and becoming less and less steep downwards. It is not capable, however, of preserving that figure; for the action of the weather, by gradually destroying the adhesion of the earth, causes the steep upper part of the concave face to crumble

down, so that the whole tends to assume a uniform curved slope in the end.

644. The Permanent Stability of earth, which is due to friction alone, is sufficient to maintain the side either of an embankment or of a cutting at a uniform slope, whose inclination to the horizon is the angle of repose, or angle whose tangent is the coefficient of friction. This is called the natural slope of the earth. The customary mode of describing the slope of earth-work is to state the ratio of the horizontal breadth to its vertical height, which is the reciprocal of the tangent of the inclination.

645. The angles of repose for different earths are given in Table XLV. But for all practical purposes it may be said that all earths, sand and gravel, stand at a slope of 33 degrees 41 minutes, or 1½ to 1. If the slopes of an excavation in sand are to be left unprotected by sodding, they should be given a slope of 2½ to 1. The ratio of slopes, their angles and length, are given in Table XLVI.

TABLE LXV.

Natural Slopes of Earths (with Horizontal Line).

Gravel (average)	40 degrees
Dry sand	38 "
Wet "	22 "
Vegetable earth	28 "
Compact earth	50 "
Shingle	39 "
Rubble	45 "
Clay (well drained)	45 "
" (wet)	16 "

TABLE LXVI.

Lengths and Angles of Slopes.

Slope.	Angle with Horizon	Length. (Height taken as 1.00.)	Slope.	Angle with Horizon	Length. (Height taken as 1.00).
¼ : 1	75° 58′	1.0307	1½ : 1	33° 41′	1.802
½ : 1	63 26	1.118	1¾ : 1	29 44	2.016
¾ : 1	53 8	1.25	2 : 1	26 34	2.236
1 : 1	45 0	1.4142	3 : 1	18 26	3.162
1¼ : 1	38 40	1.6	4 : 1	14 2	4.124

646. The inclinations generally given in practice to the various materials are as follows:

Loose earth, loam and gravel	1½ to 1
Sand	2 " 1
Soft greasy clay	3 " 1
Rock (sound)	0½ " 1

647. Effect of Moisture.—The presence of moisture in earth to an extent just sufficient to expel the air from its crevices seems to increase its coefficient of friction slightly; but any additional moisture acts like a lubricant in diminishing friction, and tends to reduce the earth to a semi-fluid condition, or to the state of mud. In this state, although it has some cohesion, or viscidity, which resists rapid alteration of form, it has no frictional stability; and its coefficient of friction and angle of repose, are each of them null.

Hence it is obvious that the frictional stability of earth depends to a great extent on the ease with which the water that it occasionally absorbs can be drained way. The safest materials for earthwork are fragments of rock, shingles, gravel, and clean sand; for these materials allow water to pass through without retaining more of it than is beneficial. The cleanest sand, however, may be made completely unstable and reduced to the state of "quick sand" if it is contained in a basin of water-holding materials so that water mixed amongst its particles cannot be drained off.

The property of retaining water and forming a paste with it belongs specially to clay, and to earths of which clay is an ingredient. Such earths, how hard and firm soever they may be when first excavated, are gradually softened, and have both their frictional stability and their adhesion diminished by exposure to the air. In this respect mixtures of sand and clay are the worst for the sand favors the access of water, and the clay prevents its escape.

The properties of earth with respect to adhesion and friction are so variable that the engineer should never trust to tables or to information obtained from books to guide him in designing earth-works, when he has it in his power to obtain the necessary data either by observation of existing earth-works in the same stratum or by experiment.

648. Inclination of Side Slopes.—The proper inclination for the side slopes of cuttings and embankments depends on the nature of the soil and the action of the atmosphere and of internal moisture upon it.

"In common soils, as ordinary garden earth formed of a mixture of clay and sand, compact clay, and compact stony soils, although the side slopes would withstand very well the effects of the weather with a steeper inclination, it is best to give them two base to one perpendicular, as the surface of the roadway will, by this arrangement, be well exposed to the action of the sun and air, which will cause rapid evaporation of the moisture of the surface. Pure sand and gravel may require a greater slope according to circumstances. In all cases where the depth of the excavation is great the base of the slope should be increased.

"In excavations through solid rock, which does not disintegrate on exposure to the atmosphere, the side might be perpendicular; but as this would exclude in a great degree the action of the sun and air, which is essential to keeping the road-surface dry and in good order, it is necessary to make the side slopes with an inclination varying from one base to one perpendicular, to one base to two perpendicular, or even greater, according to the locality; the inclination of the slopes on the south side in northern latitudes being the greater, to expose better the road-surface to the sun-rays.

"The slaty rocks generally decompose rapidly on the surface when exposed to moisture and the action of frost. The side slopes in rocks of this character may be cut into steps and then be covered by a layer of vegetable mould sown in grass-seed, or else the earth may be sodded in the usual way."

649. Form of Side Slopes.—The natural, strongest, and ultimate form of earth slopes is a concave curve, in which the flattest portion is at the bottom. This form is very rarely given to the slopes in constructing them; in fact, the reverse is often the case, the slopes being made convex, thus saving excavation for the contractor and inviting slips.

In cuttings exceeding 10 feet in depth the forming of concave slopes will materially aid in preventing slips, and in any case they will reduce the amount of material which will eventually have to be removed when cleaning up. Straight or convex slopes will continue to slip until the natural form is attained.

A revetment or retaining wall at the base of a slope will save excavation.

In excavations of considerable depth, and particularly in soils liable to slips, the slope may be formed in terraces, the horizontal offsets or benches being made a few feet in width with a ditch on the inner side to receive the surface-water from the portion of the side slope above them. These benches catch and retain earth that may fall from the slopes above them. (See Fig. 56.)

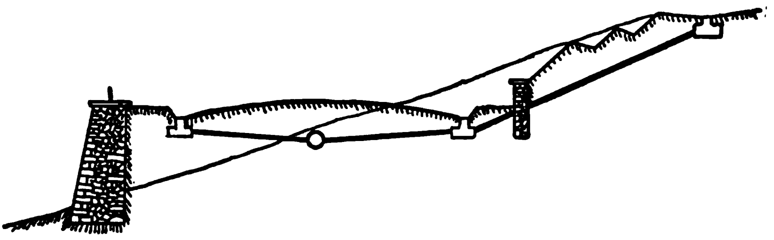


FIG. 56. HILLSIDE ROADS.

650. Covering of Slopes.—It is not usual to employ any artificial means to protect the surface of the side slopes from the action of the weather; but it is a precaution which in the end will save much labor and expense in keeping the roadways in good order. The simplest means which can be used for this purpose consists in covering the slopes with good sods, or else with a layer of vegetable mould about four inches thick, carefully laid and sown with grass-seed. These means are amply sufficient to protect the side slopes from injury when they are not exposed to any other causes of deterioration than the wash of the rain and the action of frost on the ordinary moisture retained by the soil.

A covering of brushwood or a thatch of straw may also be used with good effect; but from their perishable nature they will require frequent renewal and repairs.

"Where stone is abundant a small wall of dry stone may be constructed at the foot of the slopes to prevent any wash from them being carried into the ditches."

651. Slips.—"The stratified soils and rocks in which the strata have a dip or inclination to the horizon are liable to slips, or to give way by one stratum becoming detached and sliding on another,

which is caused either from the action of frost or from the pressure of water which insinuates itself between the strata. The worst soils of this character are those formed of alternate strata of clay and sand, particularly if the clay is of a nature to become semi-fluid when mixed with water. The best preventives that can be resorted to in these cases are to adopt a system of thorough drainage, to prevent the surface-water of the ground from running down the side slopes, and to cut off all springs which run towards the roadway from the side slopes. The surface-water may be cut off by means of a single ditch, termed a catch-water ditch, excavated a few feet back from the crest of the slope, so that it intercepts the water before it reaches the slope of the excavation, and convey it off to the most convenient natural water-courses. Usually this ditch will be required only on the up-hill side of the road; for in almost every case it will be found that the side slope on the down-hill side is, comparatively speaking, but slightly affected by the surface-water.

"Where slips occur from the action of springs, it frequently becomes a very difficult task to secure the side slopes. If the sources can be easily reached by excavating into the side slopes, drains formed of layers of fascines or brushwood may be placed to give an outlet to the water and prevent its action upon the side slopes. The fascines may be covered on top with good sods laid with the grass side beneath, and the excavation made to place the drain filled in with good earth well rammed. Drains formed of broken stone or cobbles covered in like manner on top with a layer of sod to prevent the drain from becoming choked with earth may be used under the same circumstances as fascine drains. Where the sources are not isolated and the whole mass of the soil forming the side slopes appears saturated, the drainage may be effected by excavating trenches a few feet wide at short intervals to the depth of some feet into the side slopes, and filling them with boulders or broken stone, or else a general drain of stone may be made throughout the whole extent of the side slope by excavating into it. When this is deemed necessary it will be well to arrange the drain like an inclined retaining-wall with buttresses at intervals projecting into the earth farther than the general mass of the drain. The front face of the drain should, in this case, also be covered with a layer of sods with the grass side next to the stones

forming the drain, and upon this a layer of good earth should be compactly laid to form the face of the side slopes. The drain need only be carried high enough above the toe of the side slope to tap all the sources, and it should be sunk sufficiently below the roadway to give it a secure footing."

"The drainage has been effected, in some cases, by sinking wells or shafts at some distance behind the side slopes, from the top surface to the level of the bottom of the excavation and leading the water which collects in them by pipes into the drains at the foot of the side slopes. In others a narrow trench has been excavated, parallel to the axis of the road, from the top surface to a sufficient depth to tap all the sources which flow towards the side slope, and a drain formed either by filling the trench wholly with stone or else by arranging an open conduit at the bottom to receive the water collected, over which a layer of brushwood is laid, the remainder of the trench being filled with stone."

652. Embankments.—The best materials for embankments are those whose frictional stability is the greatest and the most permanent, such as fragments of rock, shingle, gravel, and clean sand. Clay forms safe embankments, provided it is dry, or nearly dry, when laid down. Wet clay, vegetable mould, and mud are unfit for use in embankments; so also is peat, except when dry.

653. An embankment may be made in three ways: (1) In one layer. (2) In two or more thick layers. (3) In thin layers.

(1) *In One Layer.*—This being the cheapest and quickest

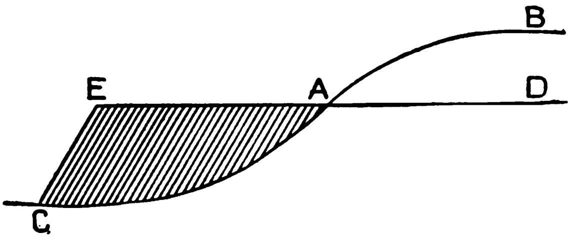


FIG. 57.

method consistent with stability, is that followed in all earth-works in which there is no special reason requiring it to be performed by the other methods. In Fig. 57 *BAC* represents the natural surface of

the ground; DA, part of the base of a cutting; AEC, an embankment the construction of which is carried forward in the direction AE of its full width and height (including a sufficient allowance for settlement), by running dump-carts on temporary tracks from the cutting along the top of the embankment, and tipping them at E, so that the earth runs down and spreads itself over the sloping end EC of the bank, which is called the "tip." Embankments formed in this manner are deficient in compactness, for the particles of earth which are emptied from the top of the bank will temporarily stop in their descent at the point of the slope at which the friction becomes sufficient to balance their gravity; and when more earth comes upon them, they will give way and slide lower down, causing the portions above them to slip and crack, and thus delay for a long time the complete consolidation.

Tipping or dumping the earth over the sides of banks made in the above manner should not be allowed, for the earth so dumped is liable afterwards to slip off.

The solidity of embankments formed in the above manner may be increased by filling from the sides towards the centre in order that the earth may arrange itself in layers with a dip from the sides inwards.

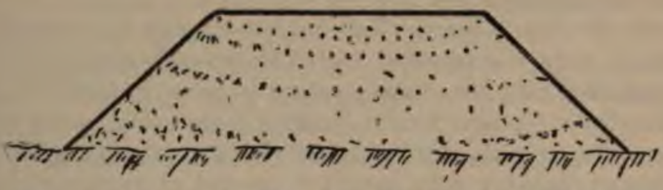


FIG. 58. CROSS-SECTION OF EARTH EMBANKMENT, SHOWING METHOD OF PLACING THE LAYERS.

As the rapidity with which a bank can be made by this method is dependent upon the number of tipping or dumping points, it is usual to form the bank wider at top and narrower at the bottom than it is finally to be, maintaining of course the requisite area of cross-section; the excess at the top (the angles AB, Fig. 59) being subsequently moved down to the bottom, thus securing the required width of base and inclination of side slopes.

It is mistaken economy to first form embankments narrow and

afterwards widen them by lateral additions, for the new material will never unite perfectly with the old.

(2) *In Thick Layers.*—This process has been used in some embankments of great height. It consists in completing the construction of the embankment up to a certain height by the process of end-dumping already described; leaving that layer for a time to settle, and then making a second layer in the same way, and so

FIG. 59.

on. It involves much additional time and labor, and is seldom employed. It is, however, useful in making embankments of hard clay or shale, which, when first dumped, consists of angular lumps that lie with vacant spaces between them and do not form a compact mass until partially softened and broken down by the action of air and moisture.

(3) *In Thin Layers.*—This process consists in spreading the earth in horizontal layers of from 9 to 18 inches deep, and rolling or ramming each layer so as to make it compact and firm before laying down the next layer. Being a tedious and costly process, it is used in special cases only, of which the principal are the filling in behind retaining walls, behind wings and abutments of bridges and culverts, and over their arches.

654. Side Slopes of Embankments.—In forming the embankments the side slopes should be made with a greater inclination than that which the earth naturally assumes, for the purpose of giving them greater durability, and to prevent the width of the top surface along which the roadway is made from diminishing by every change in the side slopes, as it would were they made with the natural slope. To protect the side slopes more effectually they should be sodded, or sown in grass-seed, and the surface water of the top should not be allowed to run down them, as it would soon wash them into gulleys and destroy the embankment. In

localities where stone is plentiful a sustaining wall of dry stone may be advantageously substituted for the side slopes.

The toe or foot of embankments has a tendency to spread; this may be resisted by excavating a small trench along the toe, or by buttressing with a low stone wall.

655. Drainage of Embankments.—The only drains required for embankments over good ground are the ordinary side ditches, with occasional culverts to convey the water from them into the natural water-courses. When springs are crossed, stone drains or culverts may be built to carry the water clear of the embankment.

656. Embankments over Plains.—When a roadway is carried across an extensive plain, it is almost always necessary, in order to keep its surface dry, that it should be raised above the general level of the ground; and where inundations occur, the requisite height may be considerable. In Fig. 60, *A* represents a cross-section of an embankment for this purpose, the materials for which are obtained by digging a pair of trenches alongside of it. These trenches, by collecting surface-water and discharging it into the nearest river or other main drainage channel, tend to shorten the duration of floods in the neighborhood of the line.

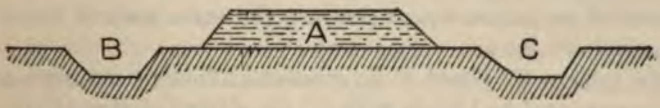


FIG. 60. SECTION OF EMBANKMENTS OVER PLAINS.

657. Embankments across Marshes.—When the ground is so soft that an embankment made in the ordinary way would sink in it, different expedients are to be employed according to the kind and degree of difficulty to be overcome. The following list of expedients is arranged in the order of an increasing scale of difficulty:

(1) By digging side drains parallel to the site of the intended embankment, the firmness of the natural ground may be increased.

(2) If the material of the natural ground has a definite angle of repose, though much flatter than that of the material of the embankment, the slopes of the embankment may be formed to the same angle, thus giving it a broader foundation than it would have with its own natural slope.

(3) A foundation may be made for the embankment by digging a trench and filling it with a stable material.

(4) The ground may be compressed and consolidated by driving short piles.

(5) The embankment may be made of materials light enough to form a sort of raft, floating on the soft ground, such as hurdles, fascines, timber platforms, or dry peat. Dry peat was the material used by George Stephenson to carry the Liverpool and Manchester Railway across Chat Moss. Its heaviness, when well dried in the air, is about 30 pounds per cubic foot; and when saturated with water, 63 pounds. On the dry-peat embankment was placed a platform of two layers of hurdles to carry the ballast.

(6) Should all other expedients fail, a marsh or bog may still be crossed by throwing in stones or gravel and sand, until an embankment is formed resting on the hard stratum below, and with its top rising to the required level. It is found that the material of the embankment assumes the same natural slope that it would do in the air.

Mr. George W. Waite, C.E., gives the following description of a road constructed by him in 1868 in the village of Hyde Park (now in the city of Chicago):

"The line crossed a marsh about one mile wide which extended from about two miles west, easterly to Lake Michigan, and south-easterly to Calumet River, a distance of two miles, and was at that time all covered with water from a few inches to two feet deep. Wild rice grew all over that portion of the marsh, about 8 feet high, and the stalks were from $\frac{1}{4}$ to $\frac{1}{8}$ inch in diameter at the bottom. Through the central portion of the marsh was an open water-way about 10 feet wide in the channel proper, with no perceptible current, which widened out into small lakes every few hundred feet.

"The channel and lakes had from 3 to 4 feet of water and about the same depth of black slush or decayed vegetable matter.

"Soundings showed the turf to be about 1 foot thick, with from 2 to 6 feet of soft black vegetable mould underneath, then a hard bottom of blue clay.

"The method of construction was as follows: Beginning at the dry ground on the south end, an 18-foot inch board, 1 foot wide, was placed lengthwise on the outside, 9 feet from the centre, then

one in the centre, 6 feet in advance of the first, and then one on the opposite side, 6 feet in advance of the middle one. Then the three pieces laid lengthwise were covered with 18-foot sound boards 1 inch thick, laid crosswise and nailed as fast as laid to keep them in their places. On these were placed three more, lengthwise as at first, one in the centre and one on each side, and these were nailed through into the under ones. Next all the wild rice for a space of about 75 feet on each side was cut down and pitched with forks onto the floating platform or roadbed. It made a compact covering about 2 feet thick. At the end of the first 500 feet a turn-around for teams on one side was made of boards doubled, 36 feet square, thoroughly nailed.

"Then the whole 500 feet of roadbed was covered 16 feet wide with about 15 inches thick of stone, and on this was placed 3 inches of crushed stone.

"After finishing the first 500 feet the turn-around was removed to the end of the second 500 feet, and so on to completion. Near the middle of the marsh was a lake which the line crossed, some 200 feet wide. This was covered with a bent bridge 50 feet long, and the balance with floats, the same as the marsh but wider. The bridge was placed on the pond-lily roots that everywhere abounded in the bottom of all these small lakes, and left about 2 feet higher than needed to allow for settling, but it has not yet settled more than some 6 inches, although a pole can be run down between the network of roots and into the slush underneath about 3 feet below the bottom of the sills before the hard bottom is reached.

"The road settled on an average about 2 feet, with the exception of two or three short distances where it settled 3 feet, but it did not break through the turf in any place. At a high stage of water some places for a few feet in length would be 1 foot under water.

"The road has stood over 23 years and has been considerably travelled, and is in good condition at the present time (1892). It has had but very little top-dressing during the whole time. Since the road was constructed the marsh has nearly all been drained and has mostly become solid, and the land in it, which at that time was not worth $25.00 per acre, has just been sold for $2500.00 per acre."

658. Embankments across Bogs.—Undrained moss consists of

about 90 per cent of water and 10 per cent of vegetable matter, and consequently while in that condition it is quite incapable of sustaining a roadway; but in most cases the surface of the underlying solid ground is above the level of the waterways of the district, and by gradual drainage the fluid mass may be condensed into a more or less solid peat. The drainage should not be effected at too rapid a rate, as there is a liability of the escaping water carrying off with it the particles of vegetable matter, causing the sides of the ditches to collapse, and producing fissures on the surface of the moss which, becoming filled with water or ice, extend more and more.

The drainage of the strip of moss along the site of the intended roadway should be effected by side drains, carried gradually down and into the solid underlying ground. And if this can be done, it is probable that the moss by conversion into peat will be reduced by about one third of its total thickness. The sides of the drains, instead of being sloped, should be cut in a series of steps or benches, each of about three feet deep and three feet broad, down to the requisite level, so as to expose as large a surface as possible to the influence of wind and sun, and thereby produce a comparatively hard skin of peat, and consequently lessen the destructive action of frost.

The side ditches should be cut parallel to the axis of the roadway and at a distance from the centre line on each side of 30 or more feet, depending upon the width of the berm intended to be left between th eedge of the roadway and the side ditch. The berm should not be less than six feet. Transverse drains should be cut at right angles to the side drains, and at distances apart not exceeding 30 feet. These transverse drains should extend across and beyond the side drains from 50 to 100 feet. The material excavated from these drains should not be deposited near their edges, or slips will probably occur; it may be spread on the roadway site. After the draining is completed, the roadway may be formed of sand and surfaced with broken stone.

659. Embankments on Hillsides.—When the axis of the roadway is laid out on the side slope of a hill, and the road is formed partly by excavating and partly by embanking, the usual and most simple method is to extend out the embankment gradually along the whole line of the excavation. This method is insecure; the

excavated material if simply deposited on the natural slope is liable to slip, and no pains should be spared to give it a secure hold, particularly at the toe of the slope. The natural surface of the slope

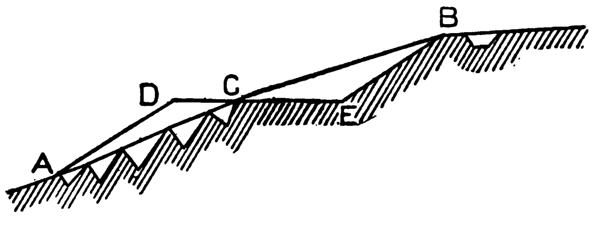


FIG. 61. SHOWING METHOD OF CONSTRUCTION ON HILLSIDES.

should be cut into steps as shown in Figs. 61, 62. The dotted line *AB* represents the natural surface of the ground, *CEB* the excavation, and *ADC* the embankment, resting on steps which have been cut between *A* and *C*. The best position for these steps is perpendicular to the axis of greatest pressure. If *AD* is inclined

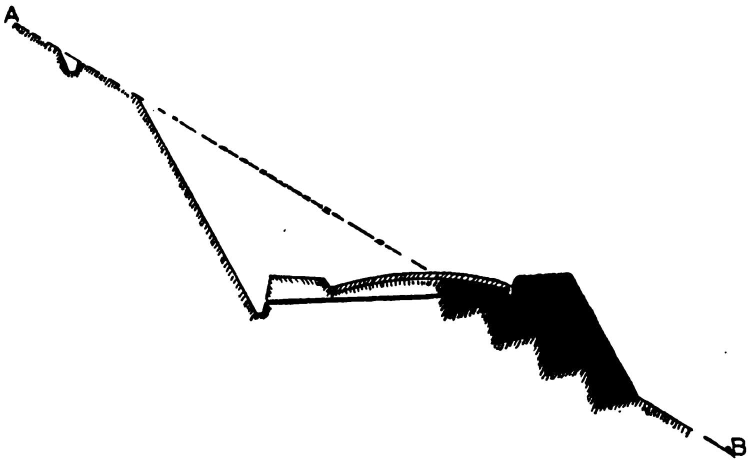


FIG. 62. SHOWING METHOD OF CONSTRUCTION ON HILLSIDES.

at the angle of repose of the material, the steps near *A* should be inclined in the opposite direction to *AD*, and at an angle of nearly

90 degrees thereto, while the steps near *C* may be level. If stone is abundant, the toe of the slope may be further secured by a dry wall of stone.

On side hills of great inclination the above method of construction will not be sufficiently secure; retaining-walls of stone must be substituted for the side slopes of both the excavations and embankments. These walls may be made of stone laid dry, when stone can be procured in blocks of sufficient size to render this kind of construction of sufficient stability to resist the pressure of the earth. But when the blocks of stone do not offer this security, they must be laid in mortar. The wall which forms the slope of the excavation should be carried up as high as the natural surface of the ground. Unless the material is such that the slope may be safely formed into steps or benches as shown in Figs. 61 and 62, the wall that sustains the embankment should be built up to the surface of the roadway, and a parapet wall or fence raised upon it, to protect pedestrians against accident. (See Figs. 56 and 63.)

660. Roadways on Rock-slopes.—On rock-slopes when the inclination of the natural surface is not greater than one perpendicular to two base, the road may be constructed partly in excavation and partly in embankment in the usual manner or, as shown in Figs. 63, 64, 65, by cutting the face of the slope into horizontal

FIG. 63. SHOWING METHOD OF CONSTRUCTION ON HILLSIDES.

steps with vertical faces, and building up the embankment in the form of a solid stone wall in horizontal courses, either dry or laid in mortar. Care is required in proportioning the steps, as all attempts

to lessen the quantity of excavation by increasing the number and diminishing the width of the steps require additional precautions against settlement in the built-up portion of the roadway.

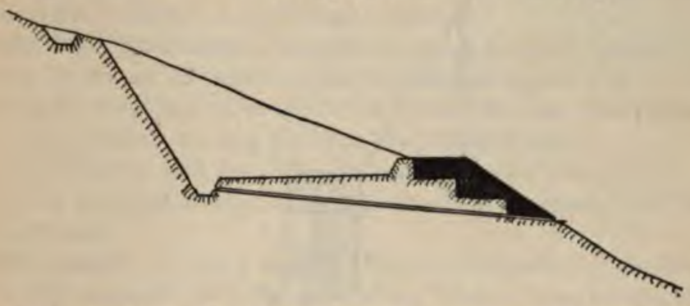


FIG. 64. SHOWING METHOD OF CONSTRUCTION ON HILLSIDES.

When the rock-slope has a greater inclination than 1 : 2 the whole of the roadway should be in excavation.

In some localities roads have been constructed along the face of nearly perpendicular cliffs on timber frameworks consisting of horizontal beams, firmly fixed at one end by being let into holes drilled in the rock, the other end being supported by an inclined strut which rests against the rock in a shoulder cut to receive it. There are also examples of similar platforms suspended instead of being supported.

661. The vertical faces of rock-cliffs present the most formidable obstacles to the formation of roads. When the rock is sufficiently hard and not liable to early disintegration a half-tunnel like *DEF*, Fig. 66, may be formed by blasting; but if it be too soft and rotten to admit of this being done, the best plan, if the cliff be of any great height *BE* above the formation level, is to blow out the whole piece *GEF* by a large mine at *E*. Mining should not, as a rule, be employed where there is a chance of the strata being blown out downwards according to the dip, for a piece may be blown out, like the shaded portion Fig. 67, when much time and expense are entailed in rectifying the level.

The general mode of attacking a vertical cliff and of forming a half-tunnel is shown in Fig. 68. The large blasts, *a*, *a*, *a*, *a*, driven 8 feet in depth, at an angle of 45 degrees, are 7 feet 3 inches apart horizontally and 5 feet vertically. The small holes, *b*, *b*, etc., 3 feet

EXAMPLES OF ROADS ON ROCK SLOPES.

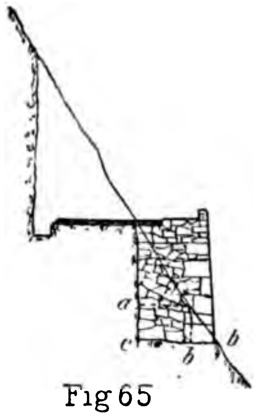


Fig 65

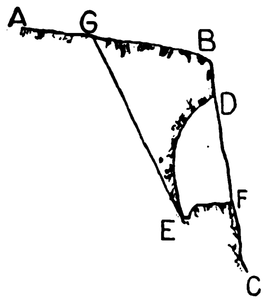


Fig 66.

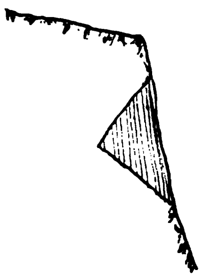


Fig. 67.

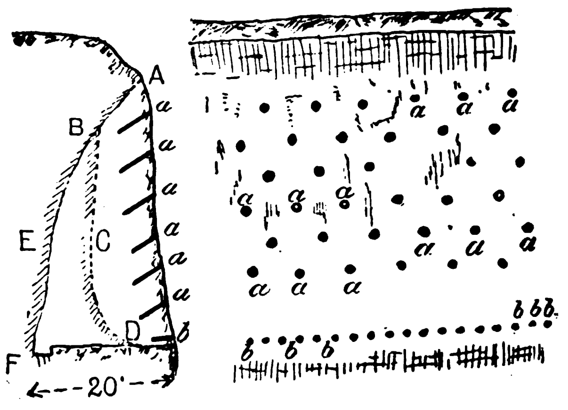


Fig. 68.

apart and 3 feet deep, which are not fired, serve to determine and facilitate rupture at the proper level. These blasts, when fired, generally blow out or loosen a piece like *ABCD*. The remaining space, *BEF*, is blown out in the same manner.

662. Rock Excavation.—Excavation in hard rock is usually performed by means of some explosive material inserted in a hole bored in the rock, and when ignited it loosens the mass and permits of its being broken up into pieces of the required size.

The diameter and depth of the hole vary with the quantity of rock to be loosened at each blast, and also with the strength of the explosive used.

The quantity of rock loosened, other conditions being the same, is roughly proportional to the cube of the "line of least resistance," which is generally the shortest distance from the centre of the charge to the surface of the rock.

If E = the quantity of the explosive in pounds, and
L = the line of least resistance in feet, then

$E = CL^3$;
$C = .032$ blasting powder;
$= .005$ " cotton;
$= .003$ nitroglycerine or dynamite.

Ordinary blasting powder, 1 pound of which occupies about 30 cubic inches, is ignited by means of a fuse, which burns at the rate of about 2 feet per minute, varying slightly with each coil.

In estimating it is usual to allow $\frac{3}{4}$ of a pound of powder to each cubic yard of solid rock. The actual quantity required will vary with the nature of the rock and its degree of compactness or looseness, the latter requiring most powder.

Dynamite and nitroglycerine should be fired by percussion. Detonating tubes or caps are made for the purpose, which explode on being ignited either by an ordinary fuze or by a galvanic battery.

663. Blasting.

If L = least line of resistance in feet;
X = number of ounces of powder required to blast any rock when $L = 2$ feet;
P = quantity of powder in ounces required,—then

$$P = \frac{XL^2}{8},$$

or, when $X = 4$ ounces,

$$P = \frac{L^2}{2}.$$

L should not exceed one half the depth of hole.

TABLE LXVII.

AMOUNT OF CHARGE WHEN $X = 4$ OUNCES.

L	Charge of Powder.		L	Charge of Powder.	
feet.	lbs.	oz.	feet.	lbs.	oz.
1	0	1	5	3	14¼
2	0	4	6	6	12
3	0	13¼	8	16	0
4	2	0			

In small blasts one pound of powder will loosen about 4½ tons.

In large blasts one pound of powder will loosen about 2¾ tons.

Thirty cubic inches of powder weigh one pound. Hence we have the following table, showing the capacity of drill-holes:

TABLE LXVIII.

CAPACITY OF DRILL-HOLES.

Diameter of Hole in inches.	Area in square inches.	Ounces of Powder in one inch deep.	Powder in one foot deep.	Depth of hole in inches to contain one lb. of Powder.
			lbs. oz.	
1	0.7854	0.419	0 5.028	38.197
1½	1.7671	0.942	0 11.300	16.976
2	3.1416	1.676	1 4.112	9.549
2½	4.9087	2.618	1 15.416	6.112
3	7.0686	3.770	2 13.240	4.244

664. In blasting no loud report should be heard nor stones be thrown out. The best effect is produced when the report is trifling, and when the mass is lifted and thoroughly fractured without the projection of fragments. If the rock be only shaken by a blast and not moved outward, a second charge in the same hole will be very effective.

Any kind of compact brush, such as pine or cedar boughs, laid on rocks about to be blasted, will almost completely prevent the flying of fragments, and thus lessen the danger to persons and buildings in the vicinity.

So much, however, depends upon the character of the rock to be excavated, whether it is hard or soft, stratified or unstratified, and whether the position of the excavation allows of arranging the drill-holes in the most advantageous manner, that the above figures must be regarded as only approximately correct.

665. Holes for blasting rock are bored either by hand or machine drills. Shallow cuts, loose boulders, etc., are more cheaply bored by hand, but deep and extensive cuttings are more economically carried out by the use of machine drills operated either by steam or compressed air.

666. Hand-drilling.—The speed with which holes may be bored in rock varies of course with the hardness of the rock and the diameter of the hole. The smaller the diameter of the hole the greater the depth that can be bored in a given time; and the depth will be greater in proportion than the decrease of the diameter.

The average rate of progress made by a good drillman working a churn-drill in granite and the harder rocks is about as follows :

Diam. of Drill. Inches.	Depth bored per hour. Inches.
3	4
2¾	5
2½	6
2	8
1¾	10

When the hole exceeds four feet in depth two men are required to operate the drill.

667. Machine-drilling.—Machine drills bore holes from ¾ to 6 inches in diameter. The rate of progress is controlled by the same conditions as hand-drilling, and ranges from three to ten feet per hour, depending on the character of the rock and the size of the machine.

668. Cost of Rock Excavation.—The cost of simply excavating rock is from four to six times that of earth, and is largely controlled by the skill of the overseer, especially as regards carrying the excavation to its full depth. If this is not done, the amount left in

the bottom, especially if it is of little depth, will cost several times more per yard to remove it than the cost per yard of the main cut.

669. Earth Excavation—Loosening the Earth.—The loosening of the material in shallow cuttings and in light soils is done best by the plough, and its removal is economically executed with drag or wheeled scrapers. Gravel, clay, and hardpan require to be loosened by the pick, or if the depth be great, explosives may be employed.

670. *Transport of Earth.*—The transport of earth is effected in the following ways:

(*a*) *Throwing with a Shovel,* when the distance horizontally does not exceed 12 feet nor vertically 6 feet.

(*b*) *Wheelbarrows* may be employed running upon a plank for distances up to 200 feet.

(*c*) *Carts.*—Between 200 and 500 feet two-wheeled dump-carts may be used.

(*d*) *Scrapers.*—The economical limit for drag-scrapers is about 150 feet. Wheeled scrapers may be employed up to 500 feet.

(*e*) For hauls over 500 feet, where a large amount of work is to be done, a track with dump-cars drawn by horses will be found profitable.

(*f*) *Dump-wagons.*—The dump-wagon is a recent invention; it consists of a four-wheeled wagon, the body of which turns on a horizontal axle, so that it can be tipped over by a single movement of a lever and the earth dumped out. Their capacity varies from 35 to 45 cubic feet. They may be economically employed in long hauls.

The distance, however, depends much upon the difficulty of getting out the earth. With hard clay, requiring two picks to a shovel, and with a small surface to work upon, two carts upon an ordinary road will take away all that a dozen men can get out; while with an easy soil, where one pick will keep half a dozen shovels busy, a larger number of vehicles will be required, or a quicker haul, which may be obtained by putting down a track. The less the haul, or the greater the speed of transport, the fewer may be the number of vehicles to remove a given amount of material. The chief point to be gained is to arrange the different classes of laborers so that none shall be kept waiting. Everything depends upon the tact for management possessed by the overseer.

671. Loosening and Transporting by Machinery.—A machine

called the New Era Grader (Fig. 205) (Chap. XXIII) has been developed for both loosening the earth and automatically transporting and depositing it in the bank when the material is obtained from side ditches, as in the case of building a bank across a plain.

The machine consists of a plough which loosens and raises the earth, depositing it upon a transverse carrying-belt, which conveys it from the excavation to the bank. The carrier-belt is of heavy three-ply rubber 3 feet wide, and can be adjusted to deliver the earth at 14, 17, 19, or 22 feet from the plough.

The machine will work in any material that can be loosened with a plough. The motive power is horses, usually twelve in number.

The capacity of the machine varies from 100 to 150 cubic yards per hour, depending upon the resistance of the material to be moved.

The number of attendants required to operate the machine is three. The cost per cubic yard loosened and placed in bank will depend upon wages and team-hire. With wages at 20 cents per hour for laborers, and horsehire at 10 cents each per hour, the cost per cubic yard would be 1.80 cents.

The machine can also be used to excavate material in deep cuts. When so employed, dump-wagons are used to transport the earth. The carrier of the machine is set to deliver at 10 feet; the wagons are driven under it and automatically loaded with from 1¼ to 1½ yards of earth in from 20 to 30 seconds. The machine can thus load from 60 to 80 wagons per hour.

672. Cost of Earth-work.—Regarding the cost of executing earthwork, no fixed rules can be given; it depends largely upon the location, kind and cost of labor, and character of the management. In general it ranges from 10 to 35 cents per cubic yard.

The several items that go to make up the total cost of earthwork are the loosening of the earth, either by ploughs, picks, or explosives, the loading it into the barrows, carts, or other vehicles, the moving and emptying it, the spreading it out upon the embankment, the return of the vehicle, the keeping of the road in order, the wear and tear of tools and vehicles, the interest on the cost of the equipment, the wages of the overseers, and the contractor's profit.

673. Haul.—The cost of removing excavated material when the

distance does not exceed a certain specified limit is included in the price per cubic yard of the material as measured in the cutting. But when the material must be carried beyond this limit, the extra distance is paid for at a stipulated price per cubic yard per 100 feet. The extra distance is known by the name of "haul," and is to be computed by the engineer with respect to so much of the material as is affected by it.

The contractor is entitled to the benefit of all short hauls (less than the specified limit), and material, so moved should not be averaged against that which is carried beyond the limit. Therefore, in all cuts the material of which is all deposited within the limiting distance, no calculation of haul is to be made.

The contractor must haul free that portion of the cutting no one yard of which is carried beyond the specified limit. Therefore this portion is first to be determined in respect to its extent, and the number of cubic yards contained in it is to be deducted from the total content of the cutting, before estimating the haul upon the remainder. Find on the profile of the line two points, one in excavation and the other in embankment, such that while the distance between them equals the specified limit, the included quantities (allowing for shrinkage) of excavation and embankment shall just balance. These points are easily found by trial with the aid of the cross-sections and calculated quantities, and become the starting points from which the haul of the remainder of the material is to be estimated.

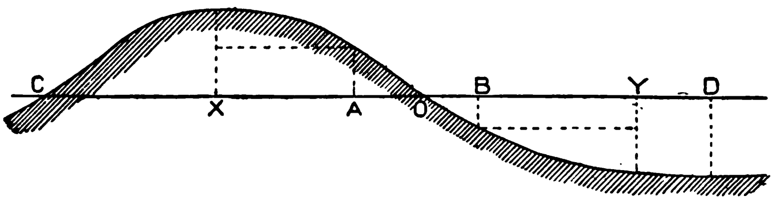


FIG. 69. ILLUSTRATING CALCULATION OF OVERHAUL.

Fig. 69 represents a cut and fill in profile. The distance *AB* is the limit of free haul. The materials taken from *AO* just make the fill *OB* and without charge for haul; but the haul for every cubic yard taken from *AC* and carried to the fill *BD* is subject

to charge for the distance it is carried, less AB. It would be impossible to find the distance that each separate yard is carried, but we know from mechanics that the average distance for the entire number of yards is the distance between the centres of gravity of the cut AC, and of the fill BD, which is made from it. If, therefore, X and Y represent the centres of gravity, the actual average haul is the sum of the distances $(AX + BY)$, and this (expressed in feet) multiplied by the number of cubic yards in the cut AC gives the product to which the price for haul applies.

If a cut is divided and parts are carried in opposite directions, the calculation of each part terminates at the dividing line. If a portion of the material in AC is wasted, it must be deducted and the haul calculated on the remainder.

The specified limit is sometimes made as low as 100 feet, sometimes as high as 1000 feet. A limit of about 300 feet, however, is usually most convenient, as it includes the wheelbarrow work and a large part of the carting, while it protects the contractor on such long hauls as may occur.

674. Calculating the Amount of Earth-work.—The quantity of excavation and embankment expressed in cubic yards is required to be known, in order to compare the amount of work to be done upon the different trial lines which may have been surveyed. For this purpose the method of averaging end areas is sufficiently exact; or if expedition is desired, the quantities may be taken from any of the many tables of quantities which for level cross-section are reliable. For other than level cross-section the tables will be in error, even with the use of the auxiliary formula given with them for the purpose of ascertaining the extra amounts to be added for irregular sections. The error in the quantities obtained by using the tables for irregular sections will be of no practical moment; in fact, it will be more an advantage by allowing a leeway of about 3 or 4 per cent in excess.

675. After final location a more accurate calculation is required, for the reason that the contractors who usually perform the work are paid, not by the day, nor in the lump, but at a certain price per cubic yard, the exact determination of which is therefore required to ascertain their just dues. For this purpose the prismoidal formula is the only one to use. It is as follows: *To the sum*

of the end areas add four times the middle area. Multiply the sum by one sixth of the length. Divide the product by 27.

676. Calculation of Half-widths and Areas.—The boundaries of a piece of earth-work in general are as follows:

(1) The base, or subgrade surface, which forms the bottom of a cutting or the top of an embankment.

(2) The original surface of the ground, which forms the top of a cutting and the bottom of an embankment.

(3) The sides, or slopes, which connect the base with the natural surface, and whose inclination is the steepest consistent with the permanent stability of the material.

677. Examples of Cross-sections.—Figs. 70 to 76 represent examples of cross-sections of pieces of earth-work, in each of which *DE* is the base, *AB* the natural surface, and *DA* and *EB* are the slopes. In Fig. 70 the natural surface is horizontal; in Figs. 73, 74, 75, 76 it slopes sideways, being what is termed "side-long ground." Figs. 71, 72 represent forms that occasionally occur. Figs. 70 to 76 represent cuttings; to represent embankments it is only necessary to conceive them to be turned upside down. Figs. 75, 76 represent pieces of earth-work, of which one side, *CEB*, is in cutting called "side cutting" and the other, *CDA*, in embankment.

The half-width of a piece of earth-work is the horizontal distance measured at right angles from a given point in the centre-line of the base to one edge of the cutting or embankment; and although it is called "half-width," it is very generally different at opposite sides of that centre line.

Each half-width consists of two parts: the real half-width of the base, which is fixed by the design of the work, and the horizontal breadth of one slope, which is to be found by calculation or by drawing.

In each of the figures 70 to 76, *C* represents a point in the centre-line, as marked on the ground; *F*, the point vertically above or below it in the centre-line of the base; *DG* and *EH* are vertical lines through the edges of the base; *DF* and *FE* are the half-widths of the base.

In Fig. 70, where the ground is level across, *GA* and *HB* are the widths of the slope, and *CA* and *CB* the half-widths of the earth-work.

In Figs. 74, 75, and 76, where the ground slopes sideways, the

EXAMPLES OF EARTH-WORK CROSS-SECTIONS.

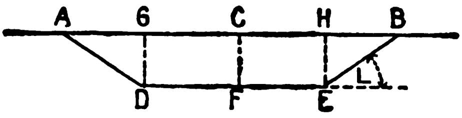


Fig. 70.

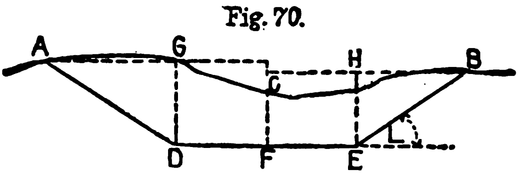


Fig. 71

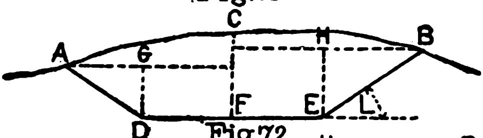


Fig. 72.

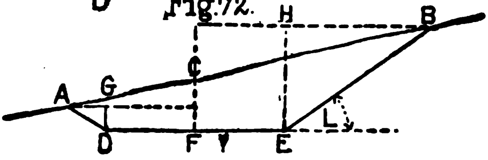


Fig. 73

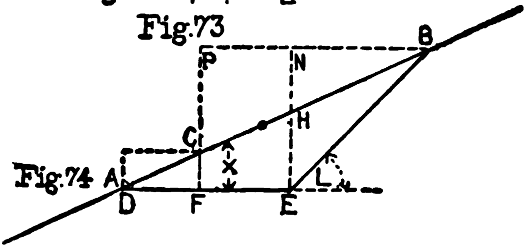


Fig. 74

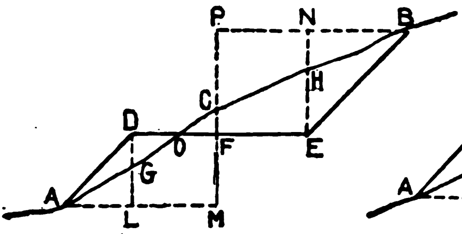


Fig. 75.

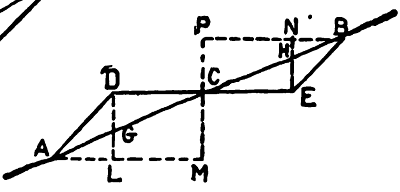


Fig. 76.

vertical lines through D, F, and E are produced, if necessary, and are cut at right angles by horizontal lines, ALM and BNP, drawn through the edges of the earth-work. AL and BN are the widths of the slopes; and MA and PB are the half-widths of the earth-work.

When the natural surface of the ground is rugged, the best method of determining the widths of the slopes is by measurement upon a series of cross-sections of the proposed work plotted to the same scale horizontally and vertically.

678. Calculation of Sectional Areas of Earth-work.—The computation of the areas of a series of cross-sections of a piece of earth-work is necessary to ascertain its volume or cubical quantity. If the ground is rugged, it may be necessary to find the area of each cross-section by measurements made upon a drawing; but if the ground is nearly or exactly level across, or has nearly or exactly a uniform sidelong slope, the area of a given cross-section can be computed from the same data which serve to compute the width of the slopes.

679. Formulas for the Calculation of Areas.

Fig. 70. $$\text{Area} = \frac{CF}{2} \cdot (AB + DE).$$

Figs. 71, 72, 73. $$\text{Area} = AB \cdot \frac{CF}{2} + \frac{DE}{4} \cdot (GD + HE).$$

Fig. 74. $$\text{Area} = \tfrac{1}{2}(\text{cotan } X - \text{cotan } V)^2 - DE^2 \cdot K.$$

(For values of K see Table LXIX.)

Fig. 75. $$\text{Area of the larger triangle} = \frac{PB + FO \cdot EH}{2}.$$

Fig. 75. $$\text{Area of the smaller triangle} = \frac{(AM - OF) \cdot DG}{2}.$$

Fig. 76. In this figure C and F coincide, that is, there is neither cut nor fill, the triangles are similar, and the area is expressed by the same formula given for Fig. 75.

The letters on Figs. 70 to 76 denote:

L = angle of side slopes with horizon.

X = angle of natural surface with horizon.

S = ratio of slopes, usually $1\frac{1}{2} : 1$.

$$S = \cot L = \frac{AG \text{ or } HB}{CF} = \frac{ABDE}{2CF}.$$

$$AG \text{ and } HB = CF \,.\, S = CF \,.\, \cot L.$$

$$AB = 2CF \,.\, S + DE.$$

TABLE LXIX.

VALUES OF K FOR DIFFERENT SLOPES. (G. L. MOLESWORTH.)

Angle of Ground. X.	Values of K.				
	¼ to 1.	½ to 1.	¾ to 1.	1 to 1.	1½ to 1.
10°	.0922	.0967	.1016	.107	.1199
12	.1123	.119	.1265	.1351	.1562
14	.1329	.1424	.1533	.1661	.1992
16	.1543	.1672	.1794	.2008	.2512
18	.1766	.1937	.2145	.2407	.3164
20	.2	.2222	.25	.2857	.4009
22	.2252	.2538	.2907	.3389	.5128
24	.25	.2857	.3342	.4012	.6702
26	.2777	.3225	.3846	.4761	.909
28	.3067	.362	.4421	.5675	1.3123
30	.3373	.4058	.5091	.6830	2.1551
32	.3703	.4545	.5882	.8333	
34	.4058	.5091	.6830	1.0373	
36	.444	.5707	.7987	1.3297	
38	.4854	.641	.9434	1.7857	
40	.5307	.7225	1.131	2.6041	
42	.5807	.8183	1.385		
44	.6364	.9345	1.754		
46	.6983	1.0729	2.315		
48	.7692	1.25			
50	.8488	1.475			

Fig. 77 shows a profile and cross-sections of a piece of earth-work.

The letters denote:

0 = a zero point, or the point at which a cutting ends and an embankment begins.

L = the distance between two parallel cross-sections.

l = the distance from a cross-section to the zero point.

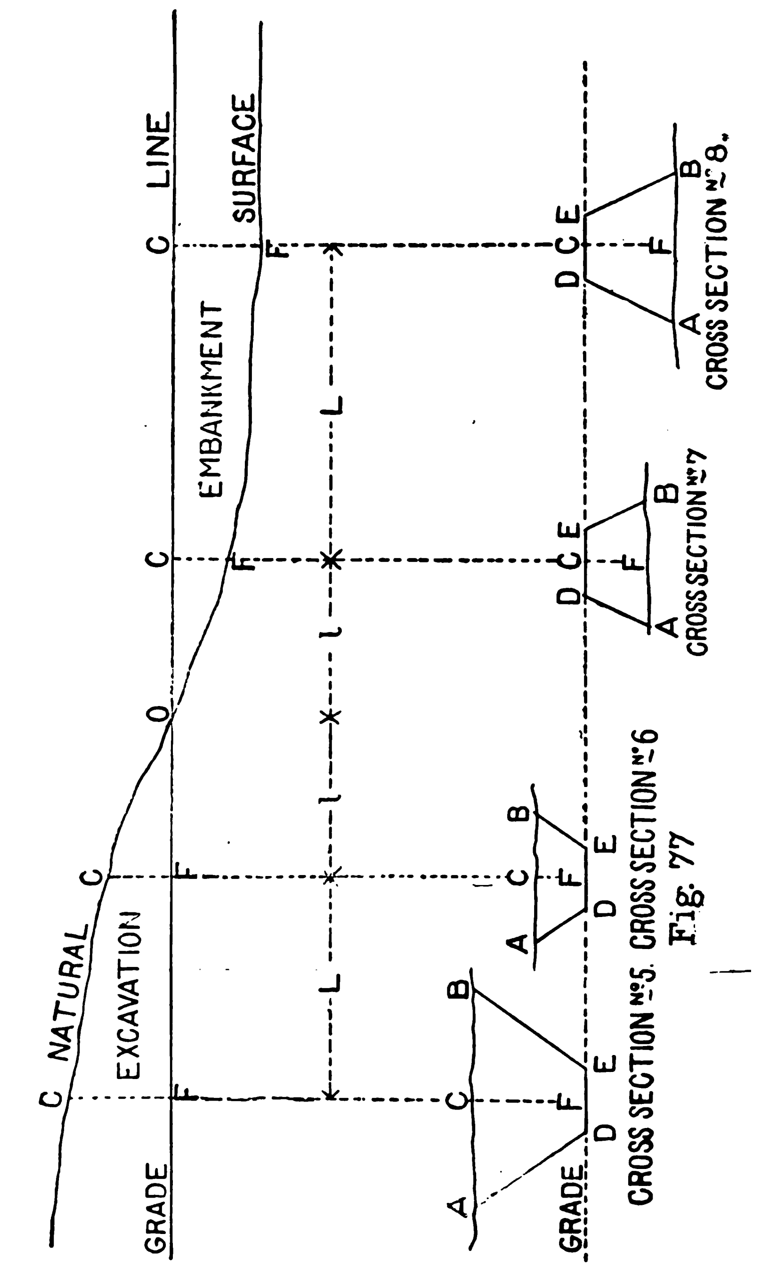

C LINE
SURFACE
EMBANKMENT
C NATURAL
EXCAVATION
GRADE
CROSS SECTION No. 5
CROSS SECTION No. 6
CROSS SECTION No. 7
CROSS SECTION No. 8.

Fig. 77

TABLE LXX.

(EARTH-WORK.)

CONTENTS OF 1-FOOT LENGTH IN CUBIC FEET.

(For lengths of 100 feet move decimal two places.)

Height. Ft.	Central Portion. Base in feet.							Contents of Both Slopes.							Height. Ft.
	20	30	33	40	50	60	66	¼ : 1	½ : 1	¾ : 1	1 : 1	1½ : 1	2 : 1	3 : 1	
1	20	30	33	40	50	60	66	.25	.5	.75	1	1.5	2	3	1
2	40	60	66	80	100	120	132	1	2	3	4	6	8	12	2
3	60	90	99	120	150	180	198	2.25	4.5	6.75	9	13.5	18	27	3
4	80	120	132	160	200	240	264	4	8	12	16	24	32	48	4
5	100	150	165	200	250	300	330	6.25	12.5	18.75	25	37.5	50	75	5
6	120	180	198	240	300	360	396	9	18	27	36	54	72	108	6
7	140	210	231	280	350	420	462	12.25	24.5	36.75	49	73.5	98	147	7
8	160	240	264	320	400	480	528	16	32	48	64	96	128	192	8
9	180	270	297	360	450	540	594	20.25	40.5	60.75	81	121.5	162	243	9
10	200	300	330	400	500	600	660	25	50	75	100	150	200	300	10
11	220	330	363	440	550	660	726	30.25	60.5	90.75	121	181.5	242	363	11
12	240	360	396	480	600	720	792	36	72	108	144	216	288	432	12
13	260	390	429	520	650	780	858	42.25	84.5	126.75	169	253.5	338	507	13
14	280	420	462	560	700	840	924	49	98	147	196	294	392	588	14
15	300	450	495	600	750	900	990	56.25	112.5	168.75	225	337.5	450	675	15
16	320	480	528	640	800	960	1056	64	128	192	256	384	512	768	16
17	340	510	561	680	850	1020	1122	72.25	144.5	216.75	289	433.5	578	867	17
18	360	540	594	720	900	1080	1188	81	162	243	324	486	648	972	18
19	380	570	627	760	950	1140	1254	90.25	180.5	270.75	361	541.5	722	1083	19
20	400	600	660	800	1000	1200	1320	100	200	300	400	600	800	1200	20
21	420	630	693	840	1050	1260	1386	110.25	220.5	330.75	441	661.5	882	1323	21
22	440	660	726	880	1100	1320	1452	121	242	363	484	726	968	1452	22
23	460	690	759	920	1150	1380	1518	132.25	264.5	396.75	529	793.5	1058	1587	23
24	480	720	792	960	1200	1440	1584	144	288	432	576	864	1152	1728	24
25	500	750	825	1000	1250	1500	1650	156.25	312.5	468.75	625	937.5	1250	1875	25
26	520	780	858	1040	1300	1560	1716	169	338	507	676	1014	1352	2028	26
27	540	810	891	1080	1350	1620	1782	182.25	364.5	546.75	729	1093.5	1458	2187	27
28	560	840	924	1120	1400	1680	1848	196	392	588	784	1176	1568	2352	28
29	580	870	957	1160	1450	1740	1914	210.25	420.5	630.75	841	1261.5	1682	2523	29
30	600	900	990	1200	1500	1800	1980	225	450	675	900	1350	1800	2700	30
31	620	930	1023	1240	1550	1860	2046	240.25	480.5	720.75	961	1441.5	1922	2883	31
32	640	960	1056	1280	1600	1920	2112	256	512	768	1024	1536	2048	3072	32
33	660	990	1089	1320	1650	1980	2178	272.25	544.5	816.75	1089	1633.5	2178	3267	33
34	680	1020	1122	1360	1700	2040	2244	289	578	867	1156	1734	2312	3468	34
35	700	1050	1155	1400	1750	2100	2310	306.25	612.5	918.75	1225	1837.5	2450	3675	35
36	720	1080	1188	1440	1800	2160	2376	324	648	972	1296	1944	2592	3888	36
37	740	1110	1221	1480	1850	2220	2442	342.25	684.5	1026.75	1369	2053.5	2738	4107	37
38	760	1140	1254	1520	1900	2280	2508	361	722	1083	1444	2166	2888	4332	38
39	780	1170	1287	1560	1950	2340	2574	380.25	760.5	1140.75	1521	2281.5	3042	4563	39
40	800	1200	1320	1600	2000	2400	2649	400	800	1200	1600	2400	3200	4800	40
41	820	1230	1353	1640	2050	2460	2706	420.25	840.5	1260.75	1681	2521.5	3362	5043	41
42	840	1260	1386	1680	2100	2520	2772	441	882	1323	1764	2646	3528	5292	42
43	860	1290	1419	1720	2150	2580	2838	462.25	924.5	1386.75	1849	2773.5	3698	5547	43
44	880	1320	1452	1760	2200	2640	2904	484	968	1452	1936	2904	3872	5808	44
45	900	1350	1485	1800	2250	2700	2970	506.25	1012.5	1518.75	2025	3037.5	4050	6075	45
46	920	1380	1518	1840	2300	2760	3036	529	1058	1587	2116	3174	4232	6348	46
47	940	1410	1551	1880	2350	2820	3102	552.25	1104.5	1656.75	2209	3313.5	4418	6627	47
48	960	1440	1584	1920	2400	2880	3168	576	1152	1728	2304	3456	4608	6912	48
49	980	1470	1617	1960	2450	2940	3234	600.25	1200.5	1800.75	2401	3601.5	4802	7203	49
50	1000	1500	1650	2000	2500	3000	3300	625	1250	1875	2500	3750	5000	7500	50

The cubical contents between sections 5 and 6 and betwe sections 7 and 8 may be ascertained by the prismoidal formula; t contents between the zero point and the continuous cross-sectio by the following formula:

$$\text{Cubic contents in feet} = l \,.\, CF\left(\frac{CF \,.\, S}{3} + \frac{DE}{2}\right).$$

680. Zero Point.—The zero point should be found on t ground. If this has not been done, it may be ascertained as follow Take the cut and the fill at the stations between which it lies; the the sum of the cut and the fill : the cut :: the distance from t cut to the fill : the distance from the cut to the zero point.

681. Earth-work Table.—Table LXX contains the contents cubic feet for each foot in length of the central portion and si slopes of embankments or cuttings. To use table, note the co tents for the central portion due to the required base and dept add contents given for the required slope and depth, and multi by the length; the product divided by 27 gives cubic yards.

CHAPTER XIV.

DRAINAGE—CULVERTS.

682. **Drainage.**—The drainage of roadways is of two kinds, viz., surface and subsurface. The first provides for the speedy removal of all water falling on the surface of the pavement; the second provides for the removal of the underground water found in the body of the road, a thorough removal of which is of the utmost importance and essential to the life of the road-covering. A road-covering placed on a wet undrained bottom will be destroyed by both water and frost, and will always be troublesome and expensive to maintain; perfect subsoil drainage is a necessity and will be found economical in the end even if it requires considerable expense to secure it.

683. The methods employed for securing the subsoil drainage must be varied according to the character of the natural soil, each kind of soil requiring different treatment.

684. The natural soils may be divided into the following classes: silicious, argillaceous, and calcareous; rock, swamps, and morasses.

685. The silicious and calcareous soils, the sandy loams and rock present no great difficulty in securing a dry and solid foundation. Ordinarily they are not retentive of water and therefore require no underdrains; ditches on each side of the road will generally be found sufficient.

686. The argillaceous soils and softer marls require more care; they retain water and are difficult to compact, except at the surface; and they are very unstable under the action of water and frost.

The drainage of these soils may be effected by transverse drains and deep side ditches of ample width. The transverse drains are placed across the road, not at right angles but in the form of an in-

verted V (∧), with the point directed up-hill; the depth at the angle point should not be less than 18 inches below the subgrade surface, and each branch should descend from the apex to the side ditches with a fall of not less than 1 inch in 5 feet. The distance apart of these drains will depend upon the wetness of the soil; in the case of very wet soil they should be at intervals of 15 feet, which may be increased to 25 feet as the ground becomes drier and firmer.

687. The transverse drains are best formed of unglazed circular tile of a diameter not less than 3 inches, jointed with loose collars. The tiles are made from terra-cotta or burnt clay, are porous, and far superior to all other kinds of drains. They carry off the water with greater ease, rarely if ever get choked up, and only require a slight inclination to keep the water moving through them.

The tiles are made in a variety of forms, as horseshoe sole, double sole, and round, the name being derived from the shape of their cross-sections. Round tile is superior to all other forms. The inside diameter of these tiles varies from 1¼ to 6 inches, but they are manufactured as large as 24 inches. Pieces of the larger pipe serve as collars for the smaller sizes. They are made in lengths of 12, 14, and 24 inches, and in thickness of shell from ¼ of an inch to 1 inch.

The collar which encircles the joint of the small tile allows a large opening, and at the same time prevents sand and silt from entering the drain. Perishable material should not be used for jointing. When laid in the ditch they should be held in place by small stones. Connections should be made by proper Y-branches.

The outlets may be formed by building a dwarf wall of brick or stone, whichever is the cheapest or most convenient in the locality. The outlet should be covered with an iron grating to prevent vermin entering the drain-pipes, building nests and thus choking up the water-way. (See Fig. 82.)

Silt-basins should be constructed at all junctions and wherever else they may be considered necessary; they may be made from a single 6-inch pipe (Fig. 83), or constructed of brick masonry as shown in Fig. 84.

The trenches for the tiles should be excavated at least 3 feet wide on top and 12 inches on the bottom. After the tiles are laid the trenches must be filled to subgrade level with round field or

cobble stones; stones with angular edges are unsuitable for this purpose. Fine gravel, sand, or soil should not be placed over the drains. Bricks and flat stones may be substituted for the tiles, and the trenches filled as above stated.

Figs. 78 to 81 show different forms of underdrains.

688. Cost of Drains per Foot.—The cost (including labor and materials) of different drains may be taken as follows:

2-inch round tile	$0.19	to	$0.28	per	foot
3- " " "	0.22	"	0.35	"	"
4- " " "	0.25	"	0.40	"	"
Triangular brick	0.22	"	0.35	"	"
Brick, 4 inches by 4 inches	0.40	"	0.95	"	"
Stone	0.35	"	0.50	"	"

Drainage with tiles will cost less than with any other material and will be more satisfactory in the end.

689. As tile-drains are more liable to injury from frost than those of either brick or stone, their ends at the side ditches should not in very cold climates be exposed directly to the weather, but may terminate in blind drains, or a few lengths of vitrified clay-pipe reaching under the road a distance of about 3 to 4 feet from the inner slope of the ditch.

690. Another method of draining the road-bed offering security from frost is by one or more rows of longitudinal drains. These drains are placed at equal distances from the side ditches and from each other, and discharge into cross-drains placed from 250 to 300 feet apart, more or less, depending on the contour of the ground. The cross-drains into which they discharge should be of ample dimensions. On these longitudinal lines of tiles the introduction of catch-basins at intervals of 50 feet will facilitate the removal of the water. These catch basins may be excavated 3 or more feet square and as deep as the tiles are laid. After the tiles are laid the pit is filled with gravel and small stones.

691. Fall of Drains.—It is a mistake to give too much fall to small drains, the only effect of which is to produce such a current through them as will wash away or undermine the ground around them, and ultimately cause their own destruction. When a drain is once closed by any obstruction no amount of fall which could be given it will again clear the passage. A drain with a considerable current through it is much more likely to be stopped from foreign

TYPES OF DRAINS.

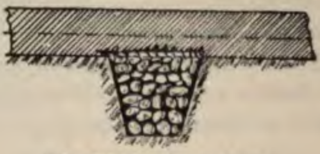


Fig. 78. BLIND DRAIN

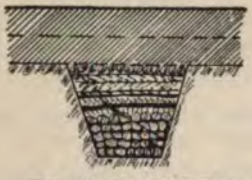


Fig. 79. POLE DRAIN

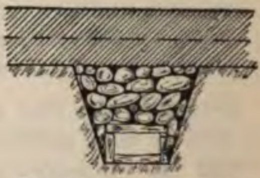


Fig. 80. STONE DRAIN

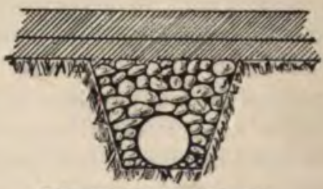


Fig. 81 TILE DRAIN.

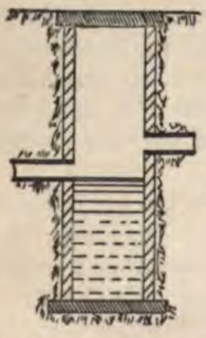


Fig. 83. PIPE SILT-BASIN

Fig. 82 DRAIN-OUTLET

Fig. 84. SILT-BASIN.

matter carried into it, which a less rapid stream could not have transported.

A fall of 1 inch in 5 feet will generally be sufficient, and 1 inch in 30 inches should never be exceeded.

692. Side Ditches.—The side ditches should be sunk 2 or 3 feet below the surface of the road. They should have sufficient capacity and declivity to receive and freely conduct away all the water that may find its way into them.

These ditches may be placed either on the road or land side of the fence. In localities where open ditches are undesirable they may be constructed as shown in Figs. 87 to 89, and may be formed of stone or tile pipe, according to the availability of either material. If for any reason two cannot be built, build one; it is better than none.

Springs found in the road-bed should be tapped and led into the side ditches.

693. Drainage of the Surface.—The drainage of the roadway surface depends upon the preservation of the cross-section, with regular and uninterrupted fall to the sides, without hollows or ruts in which water can lie, and also upon the longitudinal fall of the road. If this is not sufficient the road becomes flooded during heavy rain-storms and melting snow, and is considerably damaged.

The removal of the surface-water from country roads may be effected by the side ditches, into which, when there are no sidewalks, the water flows directly. When there are sidewalks, gutters are formed between the roadway and footpath, as shown in Figs. 85 to 90, and the water is conducted from these gutters into the side ditches by tile-pipes laid under the walk at intervals of about 50 feet. The entrance to these pipes should be protected against washing by a rough stone paving. In the case of covered ditches under the footpath, the water must be led into them by first passing through a catch-basin. These are small masonry vaults covered with iron gratings to prevent the ingress of stones, leaves, etc. Connection from the catch-basin to the ditch is made by a tile-pipe about 6 inches in diameter. The mouth of this pipe is placed a few feet above the bottom of the catch-basin, and the space below it acts as a depository for the silt carried by the water, and is cleaned out periodically. The catch-basins may be placed from 200 to 300 feet apart. They should be made of dimensions sufficient to con-

CROSS-SECTIONS OF ROADS, SHOWING METHODS OF DRAINING AND DIVISION INTO WHEELWAY, WALKS, ETC.

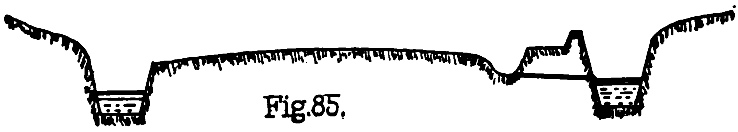


Fig.85.

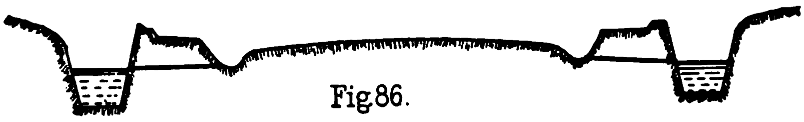


Fig.86.

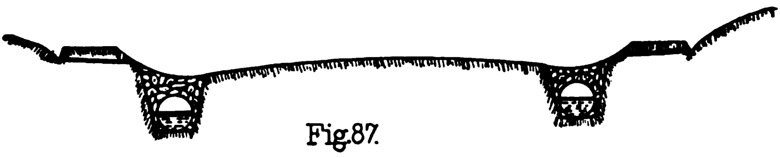


Fig.87.

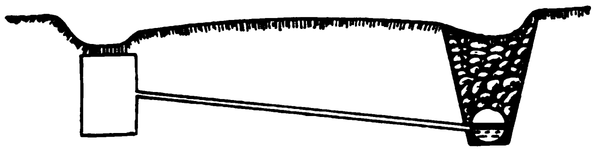


Fig.88.

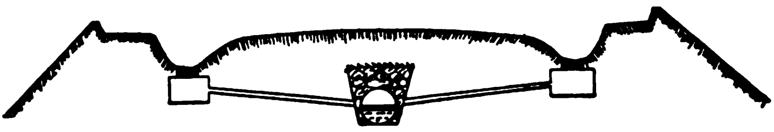


Fig.89.

vey the amount of water which is liable to flow into them during heavy and continuous rain.

694. If on inclines the velocity of the water is greater than the nature of the soil will withstand, the gutters should be roughly paved. In all cases the slope adjoining the foot-path should be covered with sod.

A velocity of 30 feet a minute will not disturb clay with sand and stone. 40 feet per minute will move coarse sand. 60 feet a minute will move gravel. 120 feet a minute will move round pebbles 1 inch in diameter, and 180 feet a minute will move angular stones $1\frac{1}{2}$ inches in diameter.

The scour in the gutters on inclines may be prevented by small weirs of stones or fascines constructed by the roadmen at a nominal cost. At junctions and cross-roads the gutters and side ditches require careful arrangement so that the water from one road may not be thrown upon another; cross-drains and culverts will be required at such places.

695. Water-breaks to turn the surface-drainage into the side ditches should not be constructed on improved roads. They increase the grade and are an impediment to convenient and easy travel. Where it is necessary that water should cross the road a culvert should be built.

696. On side hill or mountain roads catch-water ditches should be cut on the mountain side above the road, to cut off and convey the drainage of the ground above them to the neighboring ravines. The size of these ditches will be determined by the amount of rainfall, extent of drainage from the mountain which they intercept, and by the distances of the ravine water-courses on each side.

The inner road-gutter should be of ample dimensions to carry off the water reaching it; when in soil it should be roughly paved with stone. Where paving is not absolutely necessary, but it is desirable to arrest the scouring action of running water during heavy rains, stone weirs may be erected across the gutter at convenient intervals. The outer gutter need not be more than 12 inches wide and 9 inches deep. The gutter is formed by a depression in the surface of the road close to the parapet or revetted earthen protection-mound. The drainage which falls into this gutter is to be led off through the parapet, or other road-side protection at frequent intervals. The guard-stones on the outer side of the road

are to be placed in and across this gutter, just below the drainage-holes, so as to turn the current of the drainage into these holes or channels. On straight reaches with parapet protection, drainage-holes with guard-stones should be placed every 20 feet apart. Where earthen mounds are used and it may not be convenient to have the drainage-holes or channels every 20 feet, the guard-stones are to be placed in advance of the gutter to allow the drainage to pass behind them. This drainage is either to be run off at the cross-drainage of the road, or to be turned off as before by a guard-stone set across the gutter.

At re-entering turns, where the outer side of the road requires particular protection, guard-stones should be placed every 4 feet. As all re-entering turns should be protected by parapets, the drainage-holes through them may be formed as close together as desired.

697. Culverts.—Culverts are necessary for carrying under a road the streams it crosses, and also for conveying the surface-water collected in the side ditches from the upper side to that side on which the natural water-courses lie.

698. Especial care is required to provide an ample way for the water to be passed. If the culvert is too small, it is liable to cause a washout, entailing interruption of traffic and cost of repairs, and possibly may cause accidents that will require the payment of large sums for damages. On the other hand, if the culvert is made unnecessarily large, the cost of construction is needlessly increased. Any one can make a culvert large enough; but it is the province of the engineer to design one of sufficient but not extravagant size.

699. The area of water-way required depends (1) upon the rate of rainfall; (2) the kind and condition of the soil; (3) the character and inclination of the surface; (4) the condition and inclination of the bed of the stream; (5) the shape of the area to be drained, and the position of the branches of the stream; (6) the form of the mouth and the inclination of the bed of the culvert; and (7) whether it is permissible to back the water up above the culvert, thereby causing it to discharge under a head.

(1) It is the maximum rate of rainfall during the severest storms which is required in this connection. This certainly varies greatly in different sections, but there are almost no data to show what it is for any particular locality, since records generally give

CROSS-SECTIONS OF ROADS, ILLUSTRATING DRAINAGE, ETC.

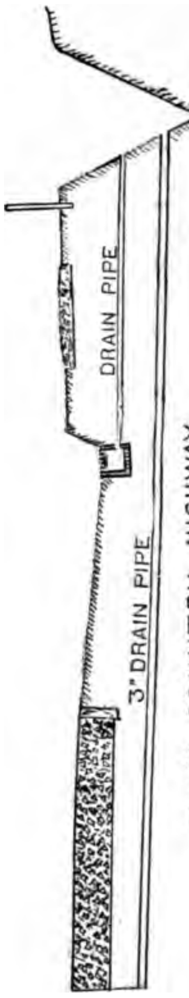


Fig. 90. COUNTRY HIGHWAY.

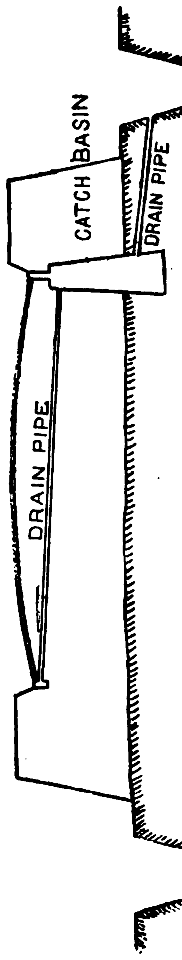


Fig. 91. ROAD IN EMBANKMENT.

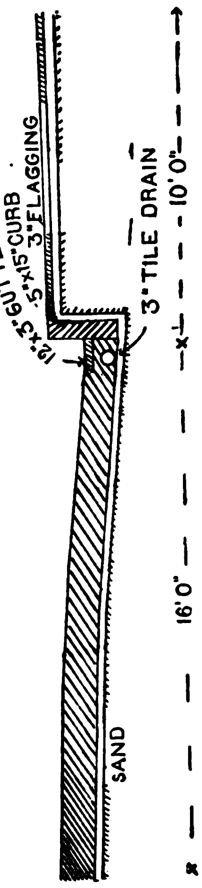


Fig. 92. SUBURBAN STREET.

the amount per day and rarely per hour, while the duration of the storm is seldom recorded. Further, probably the longer the series of observations the larger will be the maximum rate recorded, since the heavier the storm the less frequent its occurrence; and hence a record for a short period, however complete, is of but little value in this connection. Further, the severest rainfalls are of comparatively limited extent, and hence the smaller the area the larger the possible maximum precipitation. Finally, the effect of the rainfall melting snow would have to be considered in determining the maximum amount of water for a given area.

The maximum rainfall as shown by statistics is about one inch per hour (except during heavy storms), equal to 3630 cubic feet per acre. Owing to various causes, not more than 50 to 75 per cent of this amount will reach the culvert within the same hour.

Inches of rainfall $\times$ 3630 = cubic feet per acre.

Inches of rainfall $\times$ 2,323,200 = cubic feet per square mile.

(2) The amount of water to be drained off will depend upon the permeability of the surface of the ground, which will vary greatly with the kind of soil, the degree of saturation, the condition of the cultivation, the amount of vegetation, etc.

(3) The rapidity with which the water will reach the water-course depends upon whether the surface is rough or smooth, steep or flat, barren or covered with vegetation, etc.

(4) The rapidity with which the water will reach the culvert depends upon whether there is a well-defined and unobstructed channel, or whether the water finds its way in a broad thin sheet. If the water-course is unobstructed and has a considerable inclination, the water may arrive at the culvert nearly as rapidly as it falls; but if the channel is obstructed, the water may be much longer in passing the culvert than in falling.

(5) The area of the water-way depends upon the amount of the area to be drained; but in many cases the shape of this area and the position of the branches of the stream are of more importance than the amount of the territory. For example, if the area is long and narrow, the water from the lower portion may pass through the culvert before that from the upper end arrives; or, on the other hand, if the upper end of the area is steeper than the lower, the water from the former may arrive simultaneously with that from the latter. Again, if the lower part of the area is

better supplied with branches than the upper portion, the water from the former will be carried past the culvert before the arrival of that from the latter; or, on the other hand, if the upper portion is better supplied with branch water-courses than the lower, the water from the whole area may arrive at the culvert at nearly the same time. In large areas the shape of the area and the position of the water-courses are very important considerations.

(6) The efficiency of a culvert may be materially increased by so arranging the upper end that the water may enter it without being retarded. The discharging capacity of a culvert can also be increased by increasing the inclination of its bed, provided the channel below will allow the water to flow away freely after having passed the culvert.

(7) The discharging capacity of a culvert can be greatly increased by allowing the water to dam up above it. A culvert will discharge twice as much under a head of four feet as under a head of one foot. This can be done safely only with a well-constructed culvert.

700. The determination of the values of the different factors entering into the problem is almost wholly a matter of judgment. An estimate for any one of the above factors is liable to be in error from 100 to 200 per cent, or even more, and of course any result deduced from such data must be very uncertain. Fortunately, mathematical exactness is not required by the problem nor warranted by the data. The question is not one of 10 or 20 per cent of increase; for if a 2-foot pipe is insufficient, a 3-foot pipe will probably be the next size, an increase of 225 per cent; and if a 6-foot arch-culvert is too small, an 8-foot will be used, an increase of 180 per cent. The real question is whether a 2-foot pipe or an 8-foot arch-culvert is needed.

701. Calculating Area of Water-way.—Numerous empirical formulas have been proposed for this and similar problems; but at best they are all only approximate, since no formula can give accurate results with inaccurate data.

702. Mr. Rudolph Hering, C.E., gives the following formula for calculating the size of the water-way for culverts and drains:

$$Q = Cr\sqrt[4]{\frac{S}{A}},$$

in which

Q = the number of cubic feet per acre per second reaching the mouth of the culvert or drain.

C = a coefficient ranging from .31 to .75, depending upon the nature of the surface; .62 is recommended for general use.

r = average intensity of rainfall in cubic feet per acre per second.

S = the general grade of the area per thousand feet.

A = the area drained, in acres.

703. Valuable data on the proper size of any particular culvert may be obtained (1) by observing the existing openings on the same stream; (2) by measuring, preferably at time of high water, a cross-section of the stream at some narrow place; and (3) by determining the height of high water as indicated by drift and the evidence of the inhabitants of the neighborhood. With these data and a careful consideration of the various matters referred to in Art. 674, it is possible to determine the proper area of water-way with a reasonable degree of accuracy.

704. On mountain roads or roads subjected to heavy rainfall culverts of ample dimensions should be provided wherever required, and it will be more economical to construct them of masonry. In localities where boulders and other débris are likely to be washed down during wet weather, it will be a good precaution to construct catch-pools at the entrance of all culverts and cross-drains for the reception of such matter. In hard soil or rock these catch-pools will be simple well-like excavations, with their bottom two or three feet below the entrance-sill or floor of the culvert or drain. Where the soil is soft they should be lined with stone laid dry; if very soft, with masonry. The size of the catch-pools will depend upon the widths of the drainage works. They should be wide enough to prevent the drains from being injured by falling rocks and stones of a not inordinate size.

The use of catch-pools obviates the necessity of building culverts and drains at an angle to the axis of the road. Oblique structures are objectionable, as being longer than if set at right angles, and by reason of the acute- and obtuse-angled terminations to their piers, abutments, and coverings.

705. Materials for Culverts.—Culverts may be of stone, brick,

vitrified earthenware, cement, or iron pipe. Wood should be absolutely avoided.

For small streams and for a limited surface of rainfall either class of pipes, in sizes varying from 12 to 24 inches in diameter, will serve excellently. They are easily laid, and if properly bedded, with the earth tamped about them,are very permanent. Their upper surface should be at least 18 inches below the road-surface, and the upper end should be protected with stone paving so arranged that the water can in no case work in around the pipe.

When the flow of water is estimated to be too great for two lines of 24-inch pipes, a culvert is required. If stone abounds, it may be built of large roughly squared stones laid either dry or in mortar. When the span required is more than 5 feet, arch-culverts either of stone or brick masonry may be employed. For spans above 15 feet the structure required becomes a bridge.

706. Cement and Earthenware Pipe Culverts.—*Construction.*—In laying the pipe the bottom of the trench should be rounded out to fit the lower half of the body of the pipe with proper depressions for the sockets. If the ground is soft or sandy, the earth should be rammed carefully, but solidly in and around the lower part of the pipe. The top surface of the pipe should, as a rule, never be less than 18 inches below the surface of the roadway, but there are many cases where pipes have stood for several years under heavy loads with only 8 to 12 inches of earth over them. No danger from frost need be apprehended, provided the culverts are so constructed that the water is carried away from the level end. Ordinary soft drain-tiles are not in the least affected by the expansion of frost in the earth around them.

The freezing of water in the pipe, particularly if more than half full, is liable to burst it; consequently the pipe should have a sufficient fall to drain itself, and the outlet should be so low that there is no danger of back-waters reaching the pipe. If properly drained, there is no danger from frost.

Jointing.—In many cases, perhaps in most, the joints are not calked. If this is not done, there is liability of the waters being forced out at the joints and washing away the soil from around the pipe. Even if the danger is not very imminent, the joints of the larger pipes, at least, should be calked with hydraulic cement, since the cost is very small compared with the insurance against damage

ABUTMENTS FOR PIPE CULVERTS.

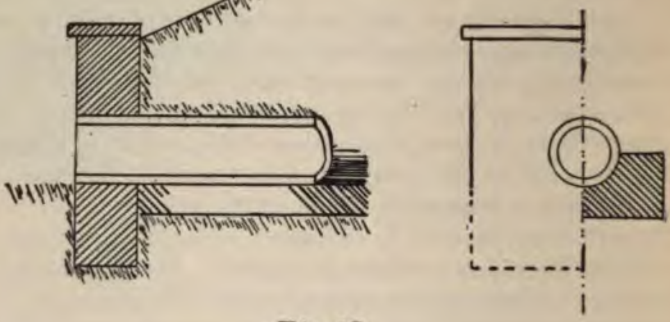


Fig. 93.

Fig 94.

Fig. 95

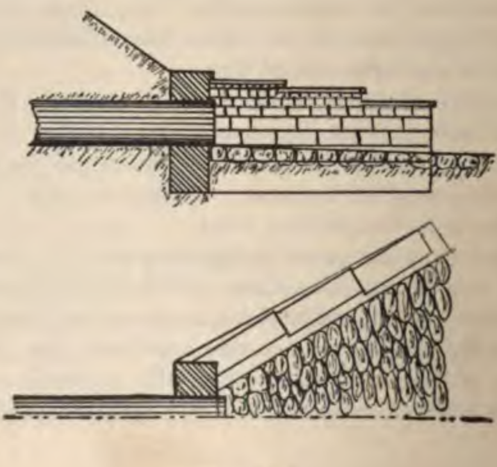


Fig. 96.

thereby secured. Sometimes the joints are calked with clay. Every culvert should be built so that it can discharge water under a head without damage to itself.

The end sections should be protected with a masonry or timber

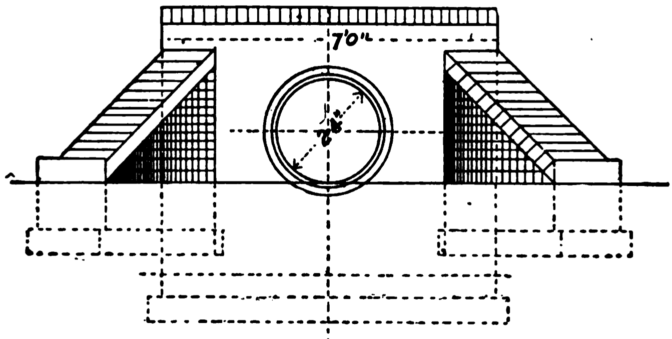


Fig. 96a. SINGLE PIPE CULVERT.

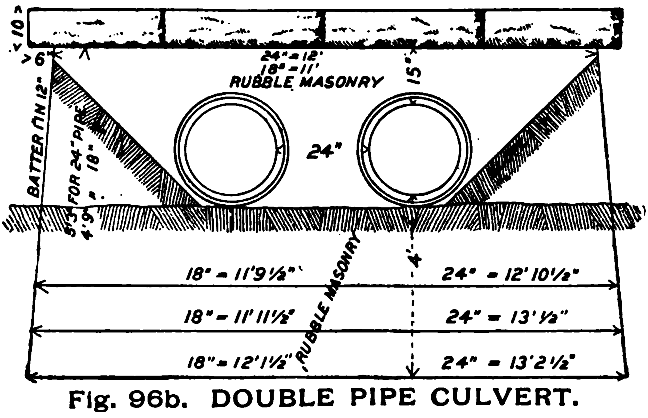


Fig. 96b. DOUBLE PIPE CULVERT.

bulkhead, although it is often omitted. A parapet wall of rubble masonry or brick-work laid in cement is best (see Fig. 93). The foundation of the bulkhead should be deep enough not to be disturbed by frost. In constructing the end wall, it is well to increase the fall near the outlet to allow for a possible settlement of the interior sections. When stone and brick abutments are too expensive, a fair substitute can be made by setting posts in the ground and spiking plank on, as shown in Fig. 95. When planks are used, it is

best to set them with considerable inclination towards the roadbed to prevent their being crowded outward by the pressure of the

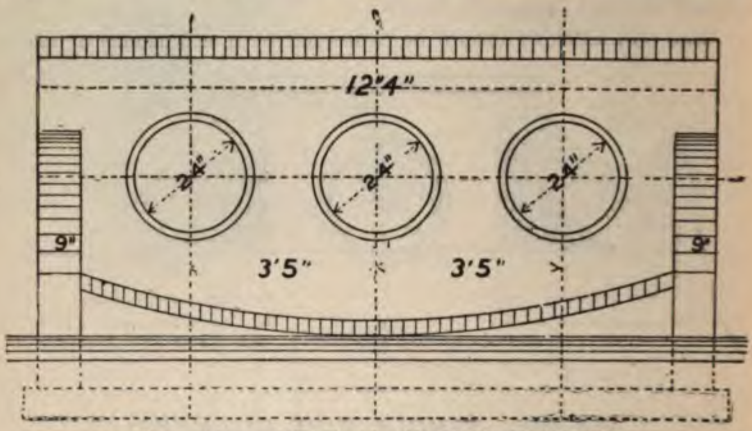


Fig. 96c. TRIPLE PIPE CULVERT.

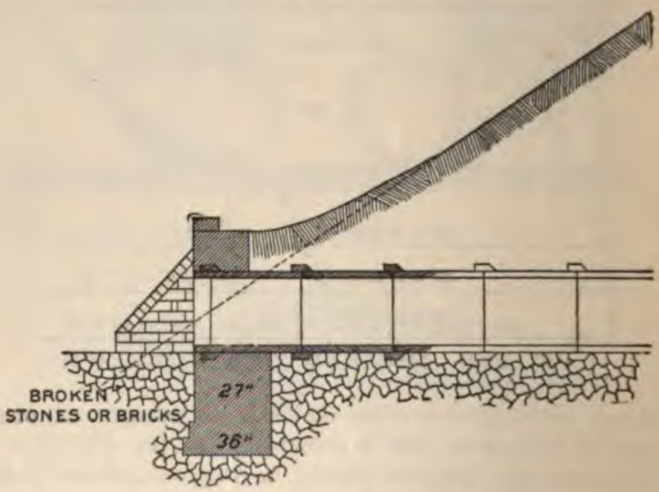


Fig. 96d. SECTION OF PIPE CULVERT.

embankment. The upper end of the culvert should be so protected that the water will not readily find its way along the outside

of the pipes, in case the mouth of the culvert should become submerged.

When the capacity of one pipe is not sufficient, two or more may be laid side by side as shown in Figs. 96a to 96c. Although two small pipes do not have as much discharging capacity as a single large one of equal cross-section, yet there is an advantage in laying two small ones side by side, since the water need not rise so high to utilize the full capacity of the two pipes as would be necessary to discharge itself through a single one of larger size.

707. Cost.—Price of earthenware and cement pipe vary greatly with the conditions of trade, and with competition and freight. Current (1892) prices, subject from 40 to 65 per cent discount for culvert-pipe in car-load lots, f. o. b. at the factory, are about as follows:

TABLE LXXI.

COST AND WEIGHT OF VITRIFIED CULVERT-PIPE.

Inside Diameter. Inches.	Price per foot. Cents.	Area. Square feet.	Weight per foot. Pounds.	Number of feet in Car-load of 24,000 lbs.
12	85	.78	48	500
15	125	1.23	67	358
18	170	1.76	84	286
20	225	2.18	99	242
24	325	3.14	140	172

TABLE LXXII.

COST AND WEIGHT OF PORTLAND CEMENT-PIPE.

Inside Diameter. Inches.	Price per foot. Cents.	Area. Square feet.	Weight per foot. Pounds.	Number of feet in Car-load of 24,000 lbs.
12	85	.78	57	450
15	125	1.23	77	320
18	178	1.76	110	230
20	225	2.18	135	180
24	325	3.14	165	150

708. Iron Pipe-culverts.—During recent years iron pipe has been used for culverts on many prominent railroads, and may be used on roads in sections where other materials are unavailable.

In constructing a culvert with cast-iron pipe the points requiring particular attention are (1) tamping the soil tightly around the pipe to prevent the water from forming a channel along the outside, and (2) protecting the ends by suitable head walls and, when necessary laying riprap at the lower end. The amount of masonry required for the end walls depends upon the relative width of the embankment and the number of sections of pipe used. For example, if the embankment is, say, 40 feet wide at the base, the culvert may consist of three 12-foot lengths of pipe and a light end wall near the toe of the bank; but if the embankment is, say, 32 feet wide, the culvert may consist of two 12-foot lengths of pipe and a comparatively heavy end wall well back from the toe of the bank. The smaller sizes of pipe usually come in 12-foot lengths, but sometimes a few 6-foot lengths are included for use in adjusting the length of the culvert to the width of the bank. The larger sizes are generally 6 feet long.

709. Cost.—Prices of cast-iron pipe vary greatly with competition and the conditions of trade. Table LXXIII shows current prices (1892), subject to commercial discount:

TABLE LXXIII.

DIMENSIONS, WEIGHT, AND PRICES OF IRON PIPE.

Inside Diameter.	Thickness.	Weight per foot.	Price per foot.
12 inches	$\frac{7}{16}$ inch	60 pounds	96 cents
16 "	$\frac{1}{2}$ "	86 "	140 "
20 "	$\frac{5}{8}$ "	118 "	188 "
24 "	$\frac{5}{8}$ "	175 "	280 "
30 "	$\frac{3}{4}$ "	240 "	384 "
36 "	$\frac{3}{4}$ "	320 "	512 "
42 "	$\frac{7}{8}$ "	400 "	640 "
48 "	1 "	510 "	616 "

710. The approximate relative cost of the different forms of culvert per lineal foot for each square foot of waterway is as follows:

Rubble.. . 40 cents
Earthenware or cement pipe........................ 30 "
Iron pipe.. 46 "

711. Stone Box-culverts.—The simplest form of stone culvert is what is known as the box-culvert. It consists of two side walls,

EXAMPLES OF BOX-CULVERTS.

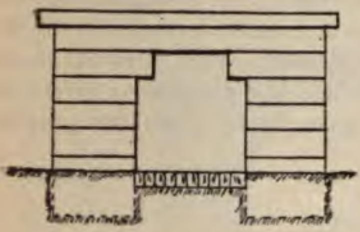


Fig. 97. END ELEVATION

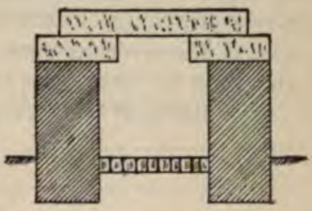


Fig. 98 SECTION AB

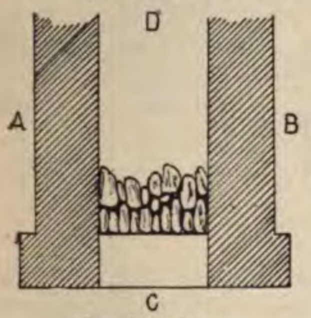


Fig 99. PLAN

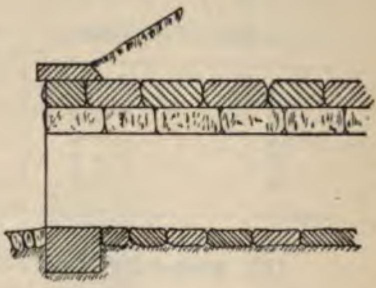


Fig. 100. SECTION CD.

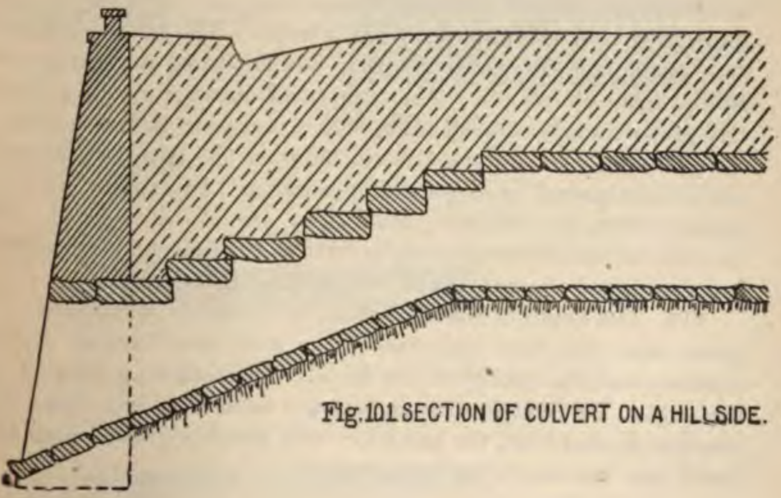


Fig. 101 SECTION OF CULVERT ON A HILLSIDE.

which may be built of stone laid dry or in mortar, and a covering of flags. Where large flat stones can readily be procured it forms a very economical structure. Under high embankments the thickness of the covering-stone must be increased. Figs. 97 to 101 show the form of this class of culverts and the dimensions given in Table LXXIV will serve as an approximate guide for general use.

TABLE LXXIV.

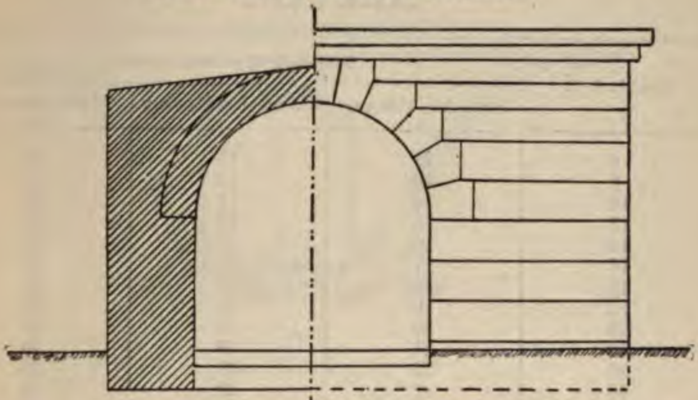
DIMENSIONS FOR BOX-CULVERTS.

Area.	Opening.	Side Wall.	Depth of Cover.	Length of Cover.
4 feet	2′ × 2′	2′ × 2′	12 inches	5 feet
9 "	3 × 3	3 × 2½	16 "	6 "
16 "	4 × 4	4 × 3	20 "	7 "
25 "	5 × 5	5 × 3½	22 "	8 "
36 "	6 × 6	6 × 4	24 "	9 "

712. Arch-culverts.—The form of an arch may be the semicircle, the segment, or a compound formed of a number of circular curves of different radii. Full-centre arches or entire semicircles offer the advantages of simplicity of form, great strength, and small lateral thrust; but if the span is large they require a correspondingly great rise, which is often objectionable. The flat or segmental arch enables us to reduce the rise, but it throws a great lateral strain on the abutments. The compound curve gives, when properly proportioned, a strong arch, with a moderate lateral action, is easily adjustable to different ratios between the span and the rise, and is unsurpassed in its general appearance. In striking the compound curve, the following conditions are to be observed: the tangents at the springing must be vertical, the tangent at the crown horizontal, and the number of centres must be uneven.

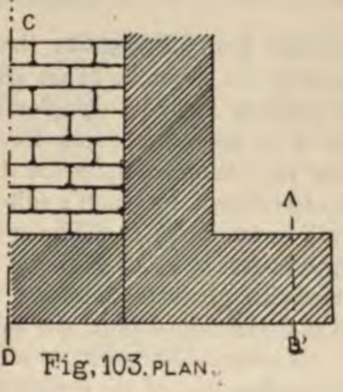
713. The depth of the arch-stone, or thickness of voussoir, depends upon the form and size of the arch, the character of the masonry, and the quality of the stone. The following table gives the depths for semicircular arches, the second column being for hammer-dressed beds, the third for beds roughly dressed with the chisel, and the fourth for brick masonry.

EXAMPLE OF ARCH-CULVERTS.

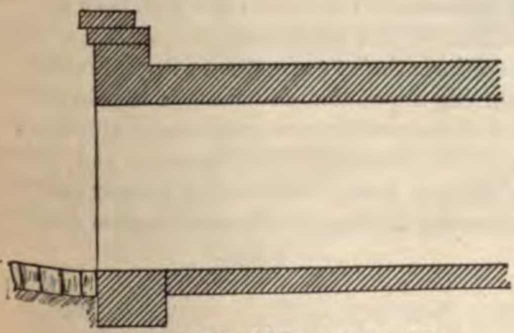


Fig, 102. SECTIONAL ELEVATION

Fig. 104. SECTION AB.



Fig, 103. PLAN.



Fig, 105 SECTION CD.

TABLE LXXV.

Span in feet.	Thickness of Arch in inches.		
	First-class Masonry.	Second-class Masonry.	Brick Masonry.
6	12	15	12
8	13	16	16
10	14	17	20
12	15	19	20
14	16	20	24
16	17	21	24
18	18	23	24
20	19	24	24
25	20	25	28
30	21	26	28
35	22	28	28
40	23	29	32
45	24	30	32
50	25	31	32

Professor Rankine remarks that the precise determination of the depth of the keystone of an arch would be an almost impracticable problem from its complexity, and that the best course in practice is to assume a depth for the keystone according to an empirical rule founded upon the dimensions of good existing examples of bridges. For such a rule he gives the following:

Depth in feet $= \sqrt{(.12 \text{ radius at crown})}$ for a single arch.

Depth in feet $= \sqrt{(.17 \text{ radius at crown})}$ for an arch of a series.

Mr. Trautwine gives the following rule: For first-class cut stone of hard material take 0.36 of the square root of the radius of the crown; for second-class work, .40 of the square root; and for brick or rubble arches, 0.45 of the square root. The results by the latter are slightly in excess of those by Professor Rankine's formula.

714. Thickness of Abutments.—Numerous rules have been given for obtaining the thickness of the abutments for arches. The most elaborate of these are from their form applied with difficulty to the cases commonly occurring in practice, and many of the elements entering into the solution of the problem are quite indeterminate, depending as they do upon the character of the masonry and upon the workmanship. In place of rules, therefore, we present merely an empirical table, embracing the results of a considerable degree of practice.

EXAMPLE OF ARCH-CULVERTS.

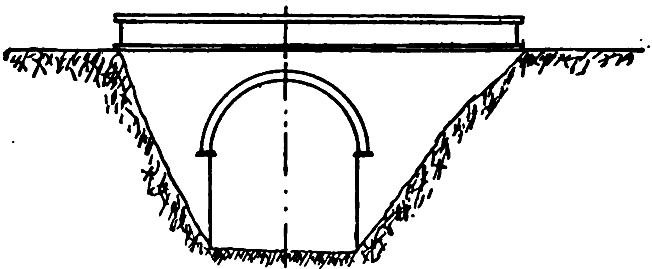


Fig. 106 END ELEVATION

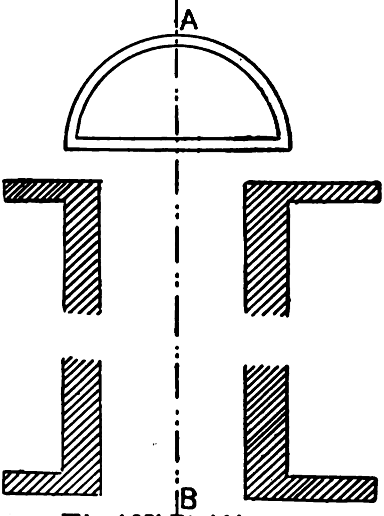


Fig. 107 PLAN

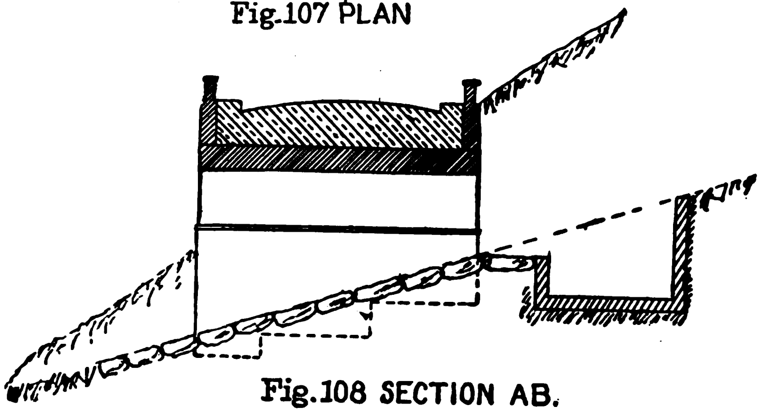


Fig. 108 SECTION AB.

Table LXXVI gives the minimum thickness of abutments fo arches of 120 degrees where the depth of crown does not exceed feet.

Calculated from the formula

$$T = \sqrt{6R + \left(\frac{3R}{2H}\right)^2} - \frac{3R}{2H},$$

in which D = depth or thickness of crown in feet;
H = height of abutment to springing in feet;
R = radius of arch at crown in feet;
T = thickness of abutment in feet.

TABLE LXXVI.

MINIMUM THICKNESS OF ABUTMENTS FOR ARCHES OF 120 DEGREES WHERE THE DEPTH OF CROWN DOES NOT EXCEED 8 FEET.

Span of Arch.	Height of Abutment to Springing, in feet.				
	5	7.5	10	20	30
8 feet	3.7	4.2	4.3	4.6	4.7
9 "	3.9	4.4	4.6	4.9	5.0
10 "	4.2	4.6	4.8	5.1	5.2
12 "	4.5	4.7	5.2	5.6	5.7
14 "	4.7	5.2	5.5	6.0	6.1
16 "	4.9	5.5	5.8	6.4	6.5
18 "	5.1	5.8	6.1	6.7	6.9
20 "	5.3	6.0	6.4	7.1	7.2
22 "	5.5	6.2	6.6	7.3	7.6
24 "	5.6	6.4	6.9	7.6	7.9
30 "	6.0	7.0	7.5	8.4	8.8
40 "	6.5	7.7	8.4	9.6	10.0
50 "	6.9	8.2	9.1	10.5	11.1
60 "	7.2	8.7	9.7	11.4	12.0
70 "	7.4	9.1	10.2	11.8	12.9
80 "	7.6	9.4	10.6	12.8	13.6
90 "	7.8	9.7	11.0	13.4	14.3
100 "	7.9	10.0	11.4	14.0	15.0

NOTE.—The thickness of abutment for a semicircular arch may be take from the above table by considering it as approximately equal to that for a arch of 120 degrees having the same radius of curvature; therefore by divid ing the span of the semicircular arch by 1.155 it will give the span of the 12 degree arch requiring the same thickness of abutment.

TABLE LXXVII.

Dimensions, Weight, and Prices of Drain-tile.

Inside Diameter. Inches.	Area in inches.	Weight per foot.	Price per 1000 feet.*	Curves and Reducers. Each.*	No. Feet to Carload.
2	3.141	3	$15.00	$0.20	8000
3	7.068	4½	25.00	0.20	6000
4	12.566	6¼	45.00	0.25	4000
5	19.625	9	75.00	0.30	3000
6	28.274	12	100.00	0.40	2200
7	38.484	15	110.00	0.50	2000
8	50.265	22	150.00	0.70	1250
9	63.617	26	200.00	0.75	1000
10	78.539	33	250.00	1.00	850
12	113.09	44	325.00	1.25	750
15	176.71	60	450.00	1.50	500
18	254.46	92	700.00	2.25	350
20	314.16	106	1000.00	3.00	250
21	345.00	110	1250.00	4.00	225
24	452.39	150	1625.00	5.00	200

* Subject to discount.

TABLE LXXVIII.

Discharging Capacity of Circular Pipes in Cubic Feet per Minute.

Diameter of Pipe.	Inclination. Inches per 100 feet.				
	3	6	9	12	24
inches	cu. ft.	cu. ft.	cu. ft.	cu. ft.	cu. ft.
2	1.71	2.54	3.07	3.61	4.95
3	3.07	4.68	5.34	6.16	8.56
4	6.28	8.82	10.82	12.43	17.51
8	35.42	30.01	61.49	70.72	100.26
9	47.46	67.24	82.48	95.05	161.23
12	97.59	138.10	170.18	196.25	277.54
15	171.37	243.04	297.32	329.41	483.55
18	270.32	383.69	468.98	540.77	749.18
20	327.54	461.23	558.82	649.73	914.43
24	555.08	784.89	962.83	1176.87	1570.05

CHAPTER XV.

BRIDGES, RETAINING-WALLS, PROTECTION WORKS, TUNNELS, FENCING.

715. Bridges.—The construction of bridges is an important subject, and should not be attempted without the professional services of a civil engineer. Neglect of this precaution, and an inadequate conception by the people of the risks to their own and other persons' lives produced by faulty bridge design, are causes to which may be attributed many of the numerous failures of highway bridges annually recorded.

As the subject is so extensive, but a few general remarks will be made in this volume.

No one bridge is adapted to every situation; each one must be designed to sustain the amount and character of the load to which it will be subjected.

716. All bridges should be proportioned to sustain the strains produced by the following loads:

(1) *The dead load*, which is the weight of the structure itself, and in certain cases some extraneous loading. The dead load is taken as uniformly distributed over the bridge.

(2) *The live load.* The live load on a bridge is the moving load passing over it. In calculating the dimensions of the several parts forming the superstructure of a bridge, the heaviest load which is likely to traverse it should be taken.

Live loads are of varied character; they comprise the weight of loaded vehicles passing either singly or in continuous strings, portable engines, agricultural machinery, steam road-rollers, and the weight of a crowd of people densely packed.

(3) The wind-pressure, including both direct and indirect effects.

(4) Variations of temperature.

Valuable information on the subject of highway bridges is to be

found in the specifications for highway bridges of iron and steel by J. A. Waddell.

717. Nothing improves the appearance and attractiveness of a road so much as a handsome bridge. And it need cost no more to construct than a homely, uncouth structure.

718. Materials for Bridges.—Bridges may be either of stone, brick, wood, steel, iron, or iron and wood. For permanence and beauty, stone or stone and brick is preferable. Steel and iron make handsome bridges, but require more attention than stone. Wood is the least permanent, and cheapest in first cost.

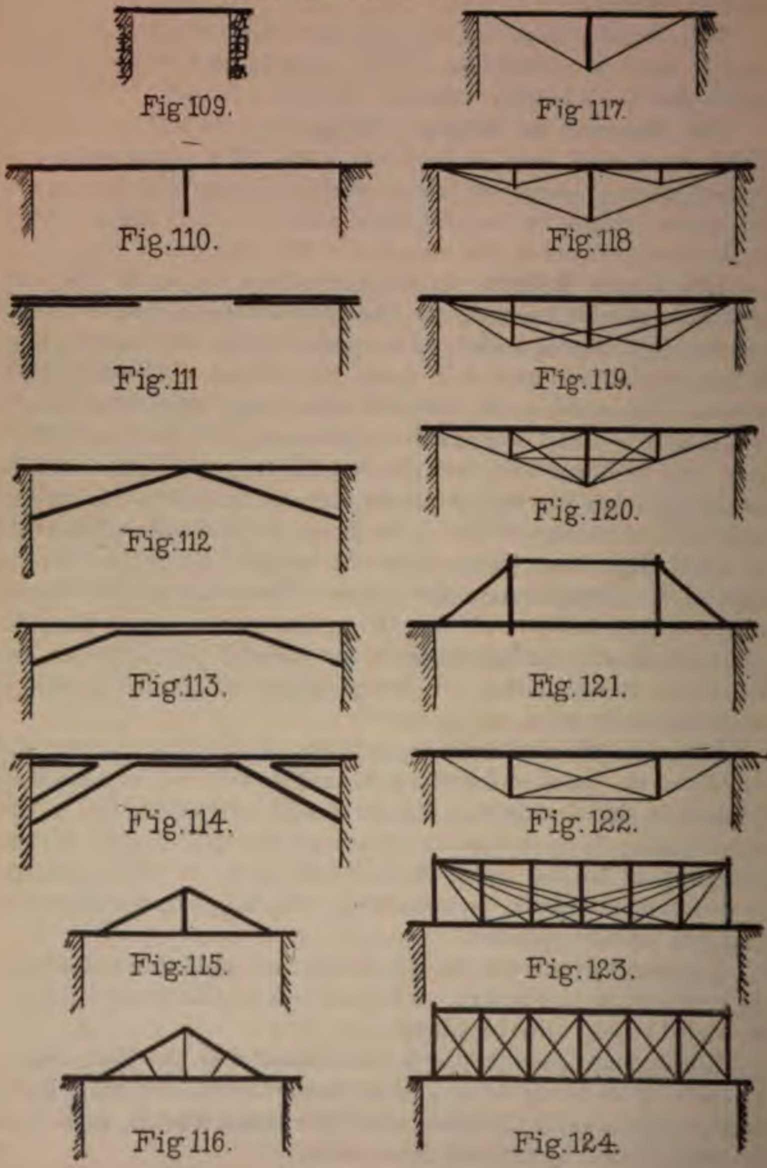
719. Timber Bridges.—In many localities timber is the only material available for bridges. Therefore a few directions for their construction may be useful. The simplest form of wooden bridge is that of plain stringers laid across the stream and covered with plank. The width of the openings which such beams span should not exceed 16 feet. For greater widths, supports in the form of piles may be introduced, thus dividing the long span into a number of shorter ones; but such supports are obstructions to the stream and liable to damage in time of freshets. It is, therefore, desirable to avoid their use. Other forms of support must therefore be devised for strengthening the beams. This may be effected by supports from below or above. Of supports from below, the simplest are shorter timbers (bolsters or corbels) placed under the main ones to which they are firmly bolted, and projecting about one third of the span.

Still more effective are oblique braces or struts supporting the middle of the beam, and resting at their lower ends in shoulders formed in the abutments. Similar braces may be applied to the bolsters (Fig. 113); but as the span increases, these braces become so oblique as to lose much of their efficiency. A straining-piece is therefore interposed between them. Openings up to thirty-five feet may thus be spanned.

For longer spans, the bolsters, braces, and straining-beams may be combined as in Fig. 114. The principle of this method may be extended to very wide openings.

But in many cases supports from below may be objectionable, as exerting too much thrust against the abutments, and being liable to be carried away by freshets, etc. The beams must in such cases be strengthened by supports from above.

TYPES OF TIMBER BRIDGES.



HEAVY LINES WOOD. LIGHT LINES IRON.

The simplest form of such is shown in Fig. 115, in which the horizontal beam is supported by an upright "king-post" to which it is attached by an iron strap, or by the upright "king-post" being formed of two pieces bolted together, and enclosing the beam between them. The king-post itself is supported by the oblique braces, or struts, which rest against notches in the horizontal beam.

Since the king-post acts as a suspending tie, an iron rod may be advantageously substituted for it; the struts may be also stiffened by iron ties, binding them to the main timbers as in Fig. 116.

For longer spans, a straining-beam may be introduced between the struts as in Fig. 121, in which the posts are represented as enclosing the beam.

The diagrams of simple bridges, Figs. 125 to 132, and Tables LXXIX and LXXX give the spans for which they may be employed and the dimensions of the several parts.

Fig. 129 shows the iron washer used at the end of the beam. The latter should be at right angles to the direction of the rod. It is better to have two rods instead of one rod under each beam. This allows the rods to be outside of the beam, as shown in the figure, instead of requiring holes to be bored through it, thereby weakening it. Fig. 130 shows the shoe used at the foot of the post and which holds the rods in place. Figs. 131 and 132 show the same method of construction applied to bridges of greater width and span.

Combination structures of wood and iron require constant watchfulness, to repair and replace damages arising from decay or defective material.

Iron Bridges.—The first cost of iron or steel bridges is greater than that of wood or combination structures; but where economy of the public funds is desired, the first two materials are to be preferred, because the annual cost of repairs to the wooden structure will in a very few years equal, if not greatly exceed, the additional sum required for the construction of the all-metal bridge. Moreover, the metal structure will outlive two if not more timber ones.

Figs. 132*a*, 132*b*, 132*c* show types of iron bridges.

To ascertain the saving in favor of iron, see Chapter XXIII.

720. The substructures of bridges should be of masonry. Timber should not be used if it can possibly be avoided. Such struc-

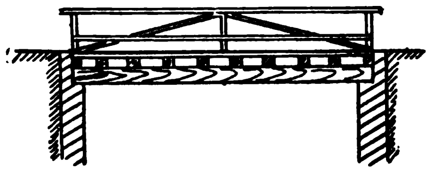


Fig. 125. LONGITUDINAL SECTION.

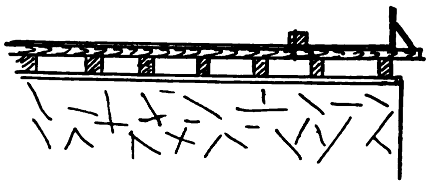


Fig. 126. TRANSVERSE SECTION.

TABLE LXXIX.

DIMENSIONS FOR FIGS. 125 AND 126.

Span. Feet.	Girders. Inches.	Floor-beams. Inches.	Floor. Inches.	Railing. Inches.
5	8 × 10	6 × 6	4	3 × 4
10	10 × 14	"	"	"
15	12 × 18	"	"	"
20	14 × 22	"	"	"

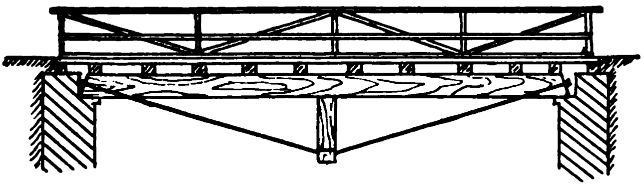


Fig. 127. LONGITUDINAL SECTION.

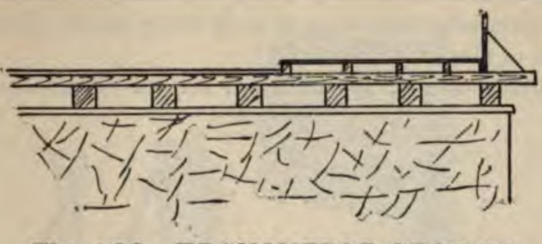


Fig. 128. TRANSVERSE SECTION.

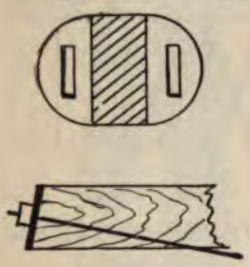


Fig. 129.
DETAIL OF WASHER.

Fig. 130.
DETAIL OF SHOE.

TABLE LXXX.

DIMENSIONS FOR FIGS. 127 TO 132.

Span. Feet.	Girders. Inches.	Diameter of Rods. Inches.	Post. Inches.
15	12 × 15	$1\frac{9}{16}$	3 × 12
20	12 × 18	$1\frac{13}{16}$	3 × 12
25	14 × 18	2	3 × 14
30	15 × 20	$2\frac{3}{16}$	4 × 15

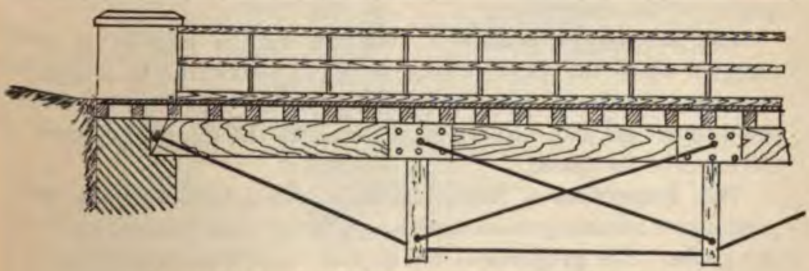


Fig. 131. LONGITUDINAL SECTION.

tures are unsatisfactory owing to early decay caused by the destroying action of air and water.

For directions and specifications for the construction of iron

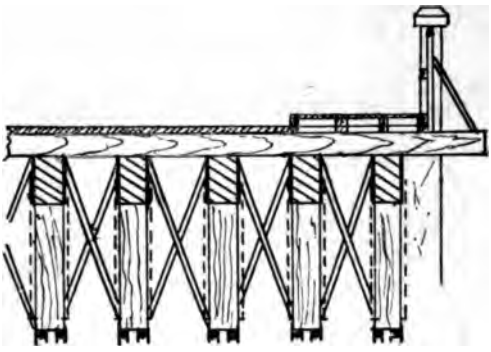


Fig. 132. TRANSVERSE SECTION.

and steel highway bridges the excellent specifications of Messrs. G. Bouscaren, Theodore Cooper, Edwin Thacher, and J. A. Waddell may be consulted.

721. Retaining-walls.—Retaining-walls are structures of stone laid dry or in mortar, and are employed under various forms to support the sides of roads on hillsides, or places where land for the slopes is not obtainable (see Figs. 133 to 136).

722. Thickness of Walls.—Retaining-walls require a certain thickness to enable them to resist being overthrown by the thrust of the material which they sustain. The amount of this thrust depends upon the height of the mass to be supported and upon the quality of the material.

723. Surcharged Walls.—A retaining-wall is said to be surcharged when the bank it retains slopes backwards to a higher level than the top of the wall; the slope of the bank may be either equal to or less, but cannot be greater, than the angle of repose of the earth of the bank.

724. Proportions of Retaining-walls.—In determining the proportions of retaining-walls experience, rather than theory, must be our guide. The proportions will depend upon the character of the material to be retained. If the material be stratified rock with in-

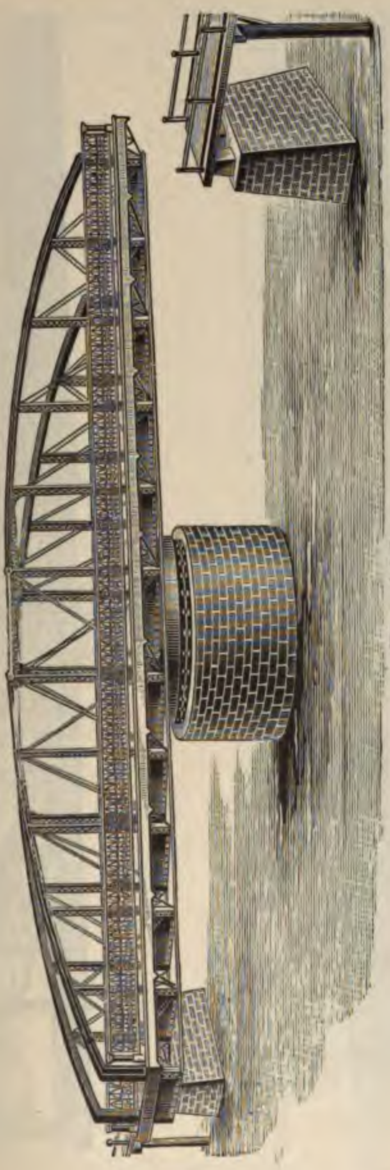


Fig. 132a.

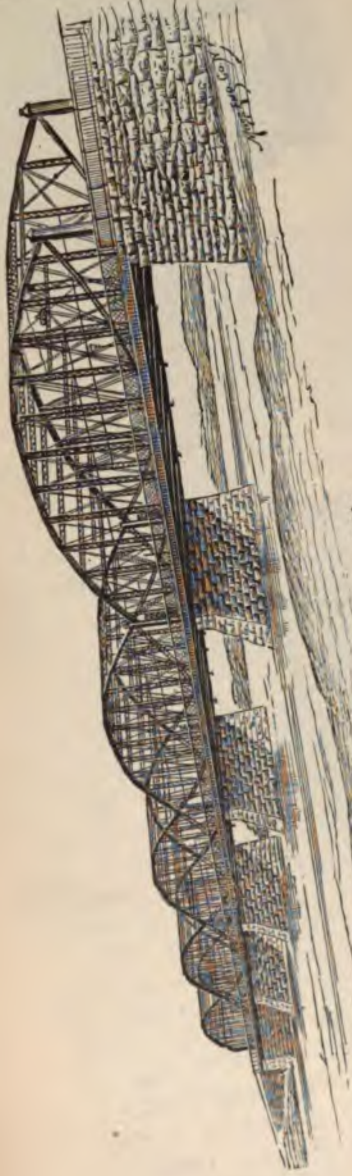


Fig. 132b.

Fig. 132c.

terposed beds of clay, earth, or sand, and if the strata incline toward the wall, it may require to be of far greater thickness than

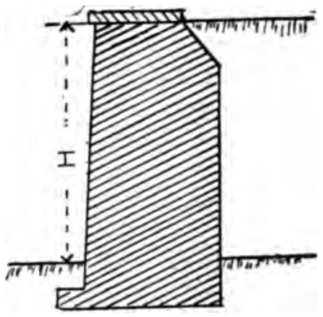


FIG. 133.

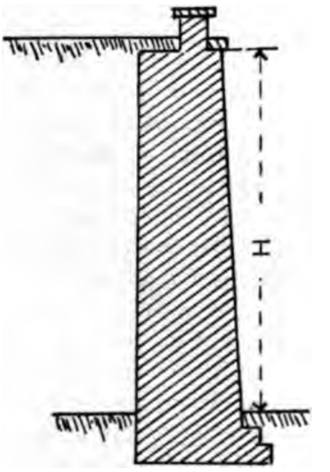


FIG. 134.

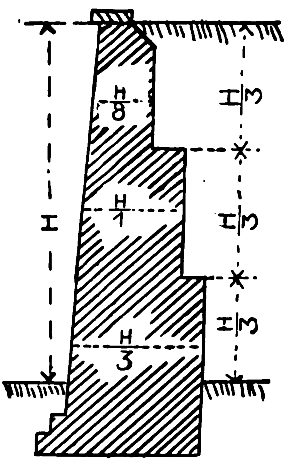


FIG. 135.

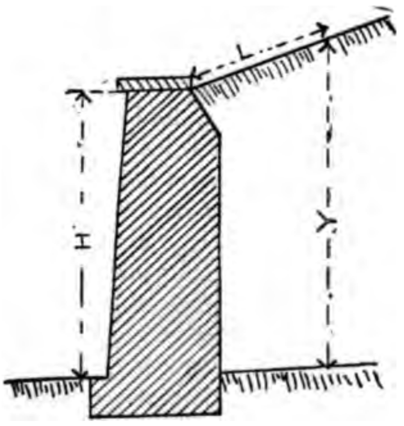


FIG. 136.

any ordinary retaining-wall; because when the thin seams of earth become softened by infiltrating rain, they act as lubricants, like

soap or tallow, to facilitate the sliding of the rock strata; and thus bring an enormous pressure against the wall. Or the rock may be set in motion by the action of frost on the clay seams. Even if there be no rock, still if the strata of soil dip toward the wall, there will always be danger of a similar result; and additional precautions must be adopted, especially when the strata reach to a much greater height than the wall.

725. Form of Retaining-walls.—Retaining-walls are built of numerous forms of profile or cross-section, varying from the rectangular to the triangular. A triangle is that figure which is theoretically the most economical; and the nearer that practical conditions will allow of its being conformed to the better.

All other things being equal, the greater the face-batter the greater will be the stability of the wall; but considerations connected with the functions of the wall limit the full application of this condition, and walls are usually constructed with only a moderate batter on the face, the diminution towards the top being obtained by a back batter worked out in a series of offsets. Walls so designed contain no more material and present greater resistance to overturning than walls with vertical backs.

726. Dry stone retaining-walls are best suited for roads on account of their self-draining properties and their cheapness. If these dry walls are properly filled in behind with stones and chips, they are, if well constructed, seldom injured or overthrown by pressure from behind. If the stone is stratified with a flat cleavage, the construction of retaining and parapet walls is much facilitated. If the stone has no natural cleavage, great care is necessary to obtain a proper bond. If walls built of such stone are of coursed rubble, care is required that the masons do not sacrifice the strength of the walls to the face appearance. The practice of building walls with square or rectangular-faced stones, tailing off behind, laid in rows, one course upon the other, the rear portions of the walls being of chips and rough stones, set anyhow, cannot be condemned too strongly. Such a construction, which is very common, has little transverse and no longitudinal strength.

Little or no earth should be used for back filling if stone is available. Where earth filling is used, it should only be thrown in and left to settle itself; on no account should it be wetted and rammed.

The foundation of retaining-walls should be particularly secure; the majority of failures which have occurred in such walls have been due to defective foundations.

727. Failure of Retaining-walls.—Retaining-walls generally fail (1) by overturning or by sliding, or (2) by bulging out of the body of the masonry. Sliding may be prevented by inclining the courses inward. An objection to this inclination of the joints in dry walls is that rain-water, falling on the battered face, is thereby carried inwards to the earth backing, which thus becomes soft and settles. This objection may be overcome by using mortar in the face-joints to the depth of a foot, or by making the face of the wall nearly vertical.

728. Protection of Retaining-walls.—The top of the walls should be protected with a coping of large heavy stones laid as headers.

Where springs occur behind or below the wall, they must be carried away by piping or otherwise got rid of.

The back of the wall should be left as rough as possible, so as to increase the friction of the earth against it.

729. Weep-holes.—In masonry walls, weep-holes must be left at frequent intervals, in very wet localities as close as 4 feet, so as to permit the free escape of any water which may find its way to the back of the wall. These holes should be about 2 inches wide and should be backed with some permeable material, such as gravel, broken stone, etc.

730. Formula for calculating Thickness of Retaining-walls.—

E = weight of earth-work per cubic yard.
W = weight of wall.
H = height of wall.
T = thickness of wall at top.
$T = H \times$ tabular number (Table LXXXI).

731. Surcharged Walls.—In calculating the strength of surcharged walls substitute Y for H, Y being the perpendicular at the end of a line, $L = H$ measured along the slope to be retained (Fig. 136).

$Y = 1.71H$ in slopes of 1 : 1;
$= 1.55H$ " " " $1\frac{1}{2}$: 1;
$= 1.35H$ " " " 2 : 1;
$= 1.31H$ " " " 3 : 1;
$= 1.24H$ " " " 4 : 1.

TABLE LXXXI.

COEFFICIENTS FOR RETAINING-WALLS.

Batter of Wall.	$E:W::4:5$		$E:W::1:1$	
	Clay.	Sand.	Clay.	Sand.
1 in 4	.083	.029	.115	.054
1 in 5	.122	.065	.155	.092
1 in 6	.149	.092	.183	.118
1 in 8	.184	.125	.218	.153
1 in 12	.221	.160	.256	.189
Vertical	.300	.239	.336	.267

732. Retaining-walls of dry stone should not be less than 3 feet thick at top, with a face of 1 in 4 and back perpendicular, the courses laid perpendicular to the face-batter. Weep-holes are unnecessary unless the walls are in very wet situations.

Retaining-walls of masonry should be at least 2 feet thick at top, back perpendicular and face battered at the rate of 1 in 6.

733. On steep hillside or mountain roads retaining-walls should be built—

(1) At all re-entering curves.

(2) At all culverts and bridges.

(3) On the edge of precipitous places, where there is no room for a bank.

(4) Where the bank slope and the ground slope are nearly or quite parallel to each other.

(5) Where a bank would be of excessive length owing to the angle of the natural ground slope.

(6) Where a wall would be cheaper than a bank.

Retaining-walls on the edge of dangerous precipices, having to support great weight, should be built of masonry. All others may be of dry stone.

734. Protection of Roads.—All roads should be protected, but hillside and mountain roads which are unprotected can only be classed as dangerous. Blocks of stone of not less than 2½ to 3 feet in height, and set with not more than 3 feet between them, afford a fair protection on a mountain road not very precipitous

at its outer edge, and there is an advantage attendant upon their use that no outer gutter is necessary, for the drainage passes over the bank in every direction, and after the first year or two but little damage occurs to the banks from this cause.

735. The proper amount of protection required for the dangerous portions of a mountain road is best obtained by stone parapets and earthen mounds. Parapets should not be less than 3 feet in height and, if of masonry, $1\frac{1}{2}$ feet in thickness.

If stone parapets be built dry, they should be at least 2 feet in thickness, and the coping should be set in mortar; otherwise they are too easily deranged, and cartmen halting on the road and desiring to block the wheels of their vehicles invariably resort to them for a stone for this purpose. Next in order of protection afforded by the use of stone may be mentioned the plan of placing large blocks of rough stone and boulders on the edge of the road and touching each other. If of good size and well set, considerable protection is afforded by this method, which is cheap. Dry stone parapet walls should never be employed if masonry walls can be afforded, and should on no account be used on precipitous curves. Parapets should be employed to protect all embankments of a road which have stone-wall revetments, and the outside of all cuttings in rock. They should also be built on each side of the road at all cross-drainage works, and should be adopted at all situations where stone is available from cuttings. Where the embankments are of earth, earthen mounds are to be preferred on the score of economy. These earthen mounds should not be less than 3 feet in height, and they are best formed, both for appearance and for their own preservation, by being revetted with dry stone inside. Earthen mounds constructed in this manner afford the most secure protection for traffic, as, if well rounded off on the outer side, they do not yield to any concussion, however violent.

736. Wooden railings should never be employed to protect dangerous places on a mountain road. They afford no real protection to the traffic, but only give a sense of protection to passing vehicles which do not come into collision with them, and show to unexcited animals that the way is barred in that direction.

737. Besides the protection so necessary for the safety of the travelling public, the roads themselves require protection at their

edges from passing vehicles. Cart-wheels, if not prevented from hugging the very edge of the road, and from slipping, either from design or accident, into the gutters, do great damage. Curb-stones get forced out of their places, and if one be displaced, others soon follow, to the destruction of the road edge as well as of the gutters themselves. These become blocked with loose stones, and when rain falls greater destruction to the road ensues. It is necessary, therefore, to protect the edges of mountain roads where they are likely to be damaged by wheel traffic, which occurs chiefly on the inside of salient and outside of re-entering curves.

738. Guard-stones about 9 inches square and of sufficient length should be placed every 4 or 5 feet apart at the curbs, clear of the

FIG. 137.

gutter, on the hill side of salient curves. The re-entering curves must also be protected on the inner curve, which is the outer side of the roadway, by means of similar guard-stones, which, however, in this situation are set up in the gutters themselves.

739. Roads along the seashore, margin of rivers and lakes, may be constructed according to either of the methods shown in Figs. 137 to 139.

In Fig. 137, two rows of piles, spaced about 10 feet centre to centre, are driven, one row along the toe of the slope and another along the crest of the slope, and capped with a 3-inch plank; between each pile and fastened thereto a 4×6 inch or heavier stringer is placed. On these stringers a layer of matched tongued and grooved plank 2 or 3 inches thick are laid and spiked.

In Fig. 138 a bulkhead is formed as follows: a row of piles, spaced 6 feet centre to centre, is driven to a solid bearing and capped with a heavy stick of timber. To the piles waling-sticks are bolted, one immediately at the head, the other at or below the

natural surface of the beach; on the land side of the waling-sticks matched sheet-piling is driven and spiked to the upper waling-stick. Anchor-piles are driven on the land side at such distance from the main piles as will form an angle of from 30 to 45 degrees. The main piles may be fastened to the anchor-piles by wrought-iron tie-rods, and bevelled cast-iron washers or timber may be used

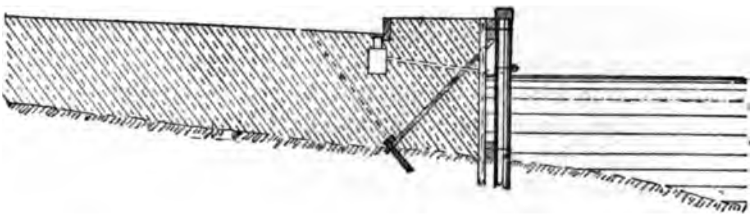


FIG. 138.

for the same purpose. A brace-stick of either round or square timber should be placed in the angle formed between the tie-rod and head of the anchor pile. The face of the main piles at high-water mark should be protected by a chafing-stick. Fender-piles may also be used if the water is navigable for large boats.

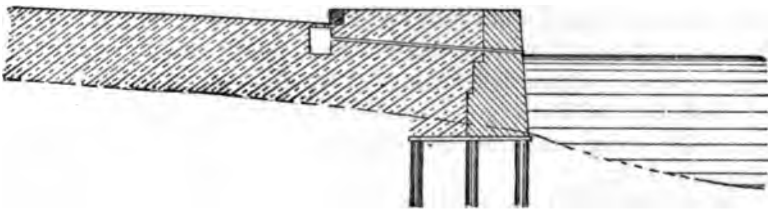


FIG. 139.

In Fig. 139 a masonry wall is shown, built on a timber platform. To this class of work the same rules apply as to retaining-walls.

740. Tunnels.—For highways, generally no tunnels can be allowed. They are too costly, and can only be employed under

exceptional circumstances. If a tunnel would shorten the road by a length, the cost of which would equal, or nearly so, the extra cost of the road through the tunnel, the construction of the tunnel would be justified. The saving in tractive energy to the public using the road would, in most cases, be a saving too indirect to be imported into the calculation.

741. Fencing.—Fences are usually built by the property-owners, but occasionally the road-builder is called upon to include fencing in his work; therefore the following few remarks may be useful. The common post and rail fence is too well known to require description; iron wire for fencing is to be had in an almost infinite variety; where stone abounds an excellent fence may be formed of the stones laid dry, with a rough coping formed of stones set edgewise in mortar. The mound and ditch shown in Fig. 140 is much used in Europe. The material excavated from the ditch is thrown

FIG. 140. DITCH AND MOUND FENCE.

into the mound and a quickset hedge planted along the top. After the lapse of some time this makes a good fence; but it requires in the interim a considerable amount of repair.

742. Cost of Fencing.—Wire, plain or barbed, with wood posts, generally cedar, chestnut, or oak, is much used in the United States.

The posts cost 10 to 25 cents each, according to distance transported.

A 4-strand wire fence with posts set 3 feet in the ground and costing 15 cents each costs per mile from \$200 to \$250.

Common board fence, posts set 8 feet apart, costs from \$350 to \$400 per mile.

An estimate for a mile of barbed-wire fence would be about as follows:

850 posts, including braces, at 10 cents	$35.00
1500 pounds 4-pointed barbed wire, at 6 cents	90 00
40 pounds of staples, at 6 cents	2.40
Labor	36.86
Freight, tools, superintendence	3.07
Total	$167.33

743. Specification for Fencing.—Posts to be oak or tamarack, 5 inches in diameter and not more than 3 inches out of straight, 8 feet 6 inches long, set 3 feet 6 inches in the ground, and spaced 16½ feet centre to centre.

Height of fence 4 feet 9 inches, formed of four strands of wire placed 12, 14, 15, and 16 inches apart, measuring from the ground.

CHAPTER XVI.

CITY STREETS.

744. The first work requiring the skill of the engineer is to properly lay out town sites, especially with reference to the future requirements of a large city where any such possibility exists. Few if any of our large cities were so planned. The same principles to a limited extent are applicable to all towns or cities. The topography of the site should be carefully studied and the street lines adapted to it; they should be laid out systematically with a view to convenience and comfort, also with reference to economy of construction, future sanitary improvements, grades, and drainage.

745. Arrangement of City Streets.—Generally straight lines, with frequent and regular intersecting streets, is the best method of laying out streets, especially for business parts of a city. When there is some centrally located structure, such as court-house, city hall, market, or other prominent public building, it is very desirable to have several diagonal streets leading thereto. In the residence portions of cities, especially if on hilly ground, curves may replace straight lines with advantage by affording better grades at less cost of grading, and improving property by avoiding heavy embankments or cuttings.

746. The rectangular arrangement of streets as seen in New York and other cities is being found objectionable and a bar to convenient communication; it therefore becomes necessary to examine what other systems, if any, may be used, and determine their relative merits. The following investigation of this subject by Mr. Lewis M. Haupt, A.M.C.E., Professor of Civil Engineering, University of Pennsylvania, is very interesting, as showing what may be done in the way of opening diagonal streets:

"The systems may be divided into two classes: 1st, regular, and 2d, irregular. The first class may be subdivided into rectangular, diagonal, and circular; the second into every possible kind of dis-

tortion more or less intricate, according to the circumstances attending the growth of a city. The latter class is discarded as being unscientific, expensive, inconvenient, and poorly adapted to the requirements of a growing community.

"As people move through a city in every conceivable direction, it will be impossible to provide the shortest lines for all; but the case may be met by supposing a greater or less number of centres or points d'appui, to and from which the currents of daily life flow and ebb.

"With reference to the subdivision of the first class, it is evident that, the straight line being the shortest distance between two points, the chord will be shorter than its arc, and hence the circular system is defective. The rectangular compels a waste of distance and time, and the diagonal by itself becomes the rectangular, so that no single system fulfils all possible requirements. A combination must therefore be resorted to, and that composed of right-line elements is both the simplest and most direct. A judicious arrangement of diagonal streets with the rectangular system will doubtless be found to meet more fully than any other the requirements of the case; but it is evident that if the streets be too wide or too numerous, the building areas will be correspondingly decreased and a certain proportion of people forced beyond given limits, thus increasing their distances. On the other hand, the diagonals will in general open new building lines with more than residences enough to provide for all the displaced inhabitants.

"To illustrate the utility of such a combination, suppose a portion of a town or city to be laid out in the form of a square whose side is L feet long, and in which the blocks are l feet square and the streets w feet wide.

"Let the diagonals of the large square be opened as thoroughfares, and note their effect. The blocks or small squares extend from the middle of one street to that of its parallel, or from the building line of one block to that of the next; hence the length of a side of such a square must be $l + w$ (Fig. 141a).

"The area of the small square, including the streets, multiplied by the number of such squares will give the area L^2 of that portion of the city, and the ratio of street to property area is the same for the small as for the large squares; but the area of the small squares is $(l + w)^2 = l^2 + 2lw + w^2$, in which l^2 is the property or build-

ing area, and $2lw + w^2$ is the street area; the ratio being $\frac{2lw + w^2}{l^2}$, and the percentage of street to property area,

$$\frac{2lw + w^2}{l^2}100. \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (A)$$

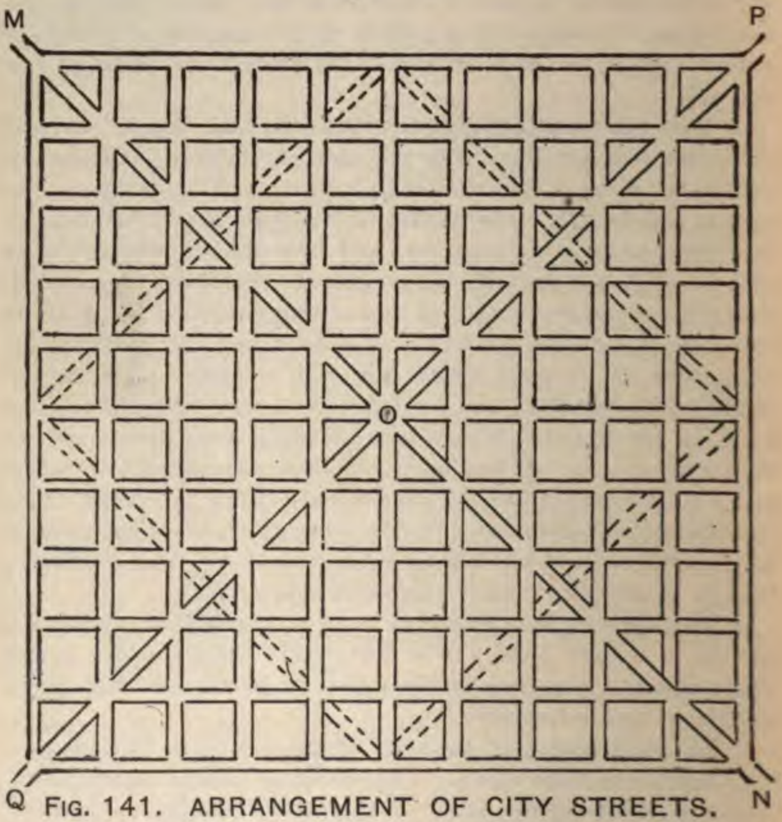


FIG. 141. ARRANGEMENT OF CITY STREETS.

For any rectangle with streets of unequal widths, the general formula would be

$$\frac{bc + ad + bd}{ac}100, \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (A')$$

in which a and c are the sides of the rectangle and b and d the widths of the streets. If these quantities are equal, each to each

(A') becomes (A). The number (n) of blocks in a given square whose area is L^2 will be

$$\frac{L^2}{(l+w)^2} = n. \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad \text{(B)}$$

"If now two diagonals, $\overline{MN}$ and $\overline{PQ}$ be introduced, it is evident that where they cross the rectangular streets no additional area is taken from the private property of the city, but they will cut out of

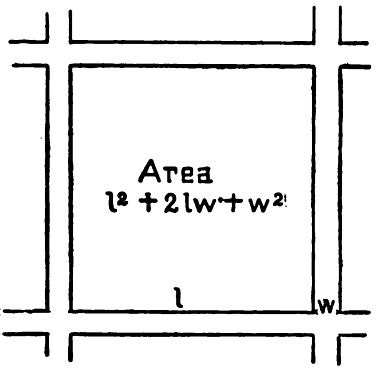


FIG. 141*a*.

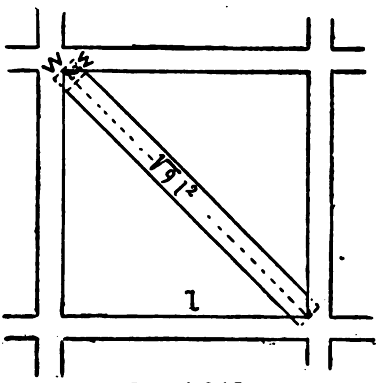


FIG. 141*b*.

each of the small squares which they cross an area whose length is $\sqrt{2l^2} - \frac{w}{2}$, breadth w, and whose area for one block, l^2, is $\left(\sqrt{2l^2} - \frac{w}{2}\right)w$ (see Fig. 141*b*). For n blocks the total building area consumed from L^2 by both diagonals when n is even will be $2nw\left(\sqrt{2l^2} - \frac{w}{2}\right)$, and the percentage of the building area will be $\frac{2nw}{n^2l^2}\left(\sqrt{2l^2} - \frac{w}{2}\right) \times 100$, which reduces to

$$\frac{w}{nl^2}(2.828l - w)100, \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad \text{(C)}$$

the formula for diagonals when n is even. If *n be odd, G* becomes

$$\frac{w}{nl^2}(2.828l)100 = 282.8\,\frac{w}{nl}. \quad . \quad . \quad . \quad . \quad . \quad \text{(C')}$$

"If diagonals be opened, benefits will accrue both from the shortening of distance and the additional frontage which will be furnished, while but a small proportion of the inhabitants will be displaced. The greatest economy in distance will be in passing from M to O (Fig. 141), which by the square system is equal to L, and by the diagonal $L\sqrt{\frac{1}{2}}$, the ratio being $\frac{L\sqrt{\frac{1}{2}}}{L} = \frac{1.4142}{2} = \frac{70}{100}$, the numerator indicating the distance (in feet) by the diagonals, the denominator by the squares. This gives a gain of 30 per cent, which is the greatest amount possible, and from which it diminishes to zero at P.

"The total length of frontage on the streets in the square system is $4ln^2$. The diagonals give an additional length of $4n(\sqrt{2l^2} - w)$, and the percentage of increase is therefore

$$\frac{l\sqrt{2} - w}{ln}100. \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \qquad \text{(D)}$$

"The ratio of people displaced is the same as that of the area consumed by diagonals to the entire area L^2.

"To determine these values for any particular case, and so discover whether or not the diagonals will be beneficial, let $l = 500$ feet, $w = 50$ feet, and $n = 10$.

"Formula (A) gives 21 as the percentage of *large or small* squares consumed by streets in the rectangular system.

"Formula (C) gives only 2.82 per cent of additional building area consumed by diagonals.

"Formula (D) gives 13 per cent as the increase in frontage due to diagonals, and it has been shown that the saving of distance varies from 30 per cent to nothing.

"The number of people displaced, which is only 2.82 per cent, will be abundantly provided for by the additional frontage on the diagonals, revenues will be augmented by assessments on the new buildings erected, and a large saving will be effected in time and distance for a majority of the inhabitants by this combination of systems, which is therefore found to fulfil the requirements of practice more fully than any other.

"Similar applications of the above formula will show to what extent the plans of cities already established or to be built may be

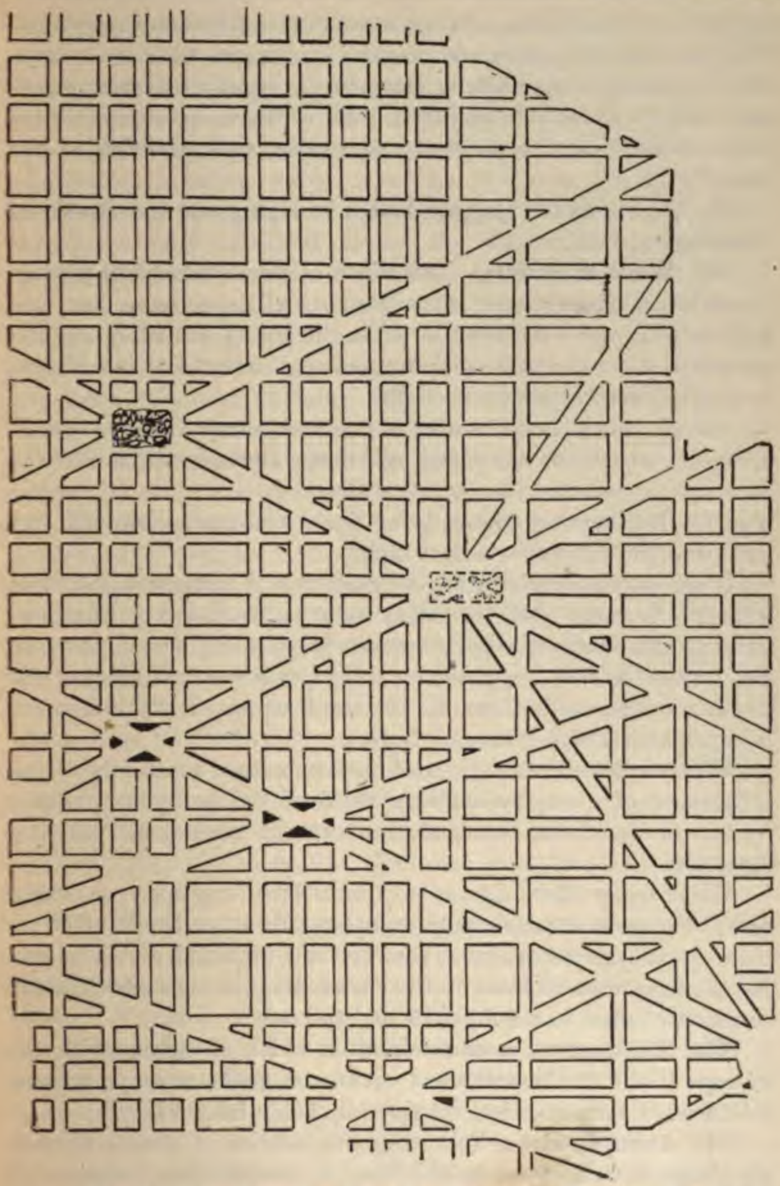


FIG. 142. ARRANGEMENT OF STREETS (PART OF WASHINGTON, D. C.)

improved by the opening of diagonals; the most economical relation of street to building area, the proper distribution of the street area, and, by extending the analysis, the ratio of pavement to carriageway may also be readily determined. All of these questions have a direct bearing on the convenience, health, and extension of our cities."

Fig. 142 shows the system adopted in laying out the streets of Washington, D. C.

747. Width of Streets.—The width of streets should be proportioned to the character of the traffic that will use them; but, as a rule, this has not been considered in the laying out of cities, and the width of the commercial thoroughfares is now found insufficient to properly accommodate the traffic.

No rule can be laid down by which to determine the best width of streets; but it may be safely said that a street which is likely to become a commercial thoroughfare should have a width of not less than 120 feet between the building lines—the carriage-way 80 feet wide, and the sidewalks 20 feet each.

In streets occupied entirely by residences a carriage-way 32 feet wide will be ample, but the width between the building lines may be as great as desired. The sidewalks may be any amount over 10 feet which the fancy may dictate. Whatever width is adopted for them, not more of it than 8 feet need be paved, the remainder being occupied with grass and trees.

Wide streets add materially to the commercial prosperity of the inhabitants of a city by relieving them of the heavy tax imposed by narrow streets on transportation through constantly recurring blockades.

Wide streets afford a good amount of breathing space, and thus add to the general health of the people. Moreover, they contribute to a city an air of spacious comfort and dignified distance, and for all time remove from it the crowded appearance which is too commonly found in all old cities and towns.

748. The maximum and minimum width of streets, with the average width of sidewalks and maximum grade, as at present established in various cities, are given in Table LXXXII.

749. Street Grades.—Following the location of streets, there is the important duty of establishing a comprehensive system of grades. If this could always be done in advance of improvements,

there would be little difficulty in obtaining the best grades for a city. Unfortunately this is seldom the case, and in adjusting the street grades of villages in process of transformation into towns the engineer encounters one of his most trying duties; he meets much opposition from the property-owners who have made improvements based upon the natural slopes, also from those who object to having a street in excavation where it passes through their lands. Each one is looking to his individual interest, and he must exercise much discretion and endeavor to fix a system of grades harmonious, convenient, and economical for the public rather than for individuals.

Every town that expects to thrive should at a very early stage in its history establish the grades of its streets to the full extent of the town plot, and in doing so keep in view the probability of future extension. In new towns this ought to be done when the town is laid out, and the grades might be made part of the original record.

750. No rule can be laid down for determining the proper grades for city streets. They will depend upon the topographical features of the site. The necessity of avoiding deep cuttings or high embankments which would seriously affect the value of adjoining property for building purposes often demands steeper grades than are permissible on country roads. There are, however, certain conditions which it is important to attain: first, that the longitudinal crown level be uniformly sustained from street to street whenever practicable, so as to avoid undulations; second, that the crown level at all intersections be extended transversely to avoid the necessity of driving over a channel, which is otherwise formed.

Table LXXXII shows the maximum grade of streets in several cities.

751. The best arrangement of intersections of streets when either or both have much inclination is a matter requiring much consideration and is one upon which much diversity of opinion exists. No hard or fast rule can be laid down; each will require special adjustment. The best and simplest method is to make the rectangular space *aaaaaaaa*, Fig. 143, level with a rise of one-half inch in 10 feet from *AAAA* to *B*, placing gulleys at *AAAA* and the catch-basins at *cccc*. When this method is not practicable, adopt such a grade (but one not exceeding $2\frac{1}{2}$ per cent) that the rectangle *AAAA*, Fig. 143, shall appear to be nearly level; but to secure this

TABLE LXXXII.

Width of City Streets.

City of	Width of Streets between Building Lines. Maximum. Feet.	Width of Streets between Building Lines. Minimum. Feet.	Maximum Grade. Feet per 100 feet.	Average Width of Sidewalks. Feet.
New York, N. Y........	100	60	13	15
Brooklyn, N. Y..........	100	60	12	18
Buffalo, N. Y............	100	40	7	23
Syracuse, N. Y	120	33	20	
Elmira, N. Y	100	33	5	14
Schenectady, N. Y.... .	90	20	8	
Boston, Mass				7
Lynn, Mass..............	100	50	17.21	8
Worcester, Mass.	100	20	20	17
Lowell, Mass............	70	30	16	14
Cambridge, Mass.........	102	26	11.66	8
Chicago, Ill..............	150	30	2.40	25 to 4
Bloomington, Ill.........	100	30	4.80	
Jersey City, N. J.........	80	30	14	
Camden, N. J......	100	26	3	15
Newark, N. J............	132	40	10	10
Trenton, N. J............	80	30	8	16 to 6
Paterson, N. J...........	120	40	17	
Terre Haute, Ind........	99	50	5	
Richmond, Va......... ..	118	30	3	
Omaha, Neb.............	120	40	15	13
Nashville, Tenn	104	20	11	17
Parkersburg, W. Va......	60	40		
Washington, D. C........	160	80		
Wilmington, N. C........	99	30	9	17
Seattle, Wash......... ...	120	60		16 to 8
Philadelphia, Pa.........	120	30	16	
Pittsburg, Pa............	100	30	15½	⅖ width of
Erie, Pa..................	100	50		20 to 12
Harrisburg, Pa...........	120	20	7	⅕ width of
Providence, R. I........	225	10	19	⅙ "
Cumberland, Md.........	65	20	10	
Hartford, Conn	70	25	6	6 to 4
Waterbury, Conn.........	160	28	13	6
New Haven, Conn.	100	40	12	20 to 8
Detroit, Mich............	120	36	5	20 to 6
Grand Rapids, Mich......	100	50	12	12 to 4
St. Paul, Minn...........	200	50		
Minneapolis, Minn.	120	60		27
Bucyrus, Ohio...........	82½	40		16
Salt Lake City, Utah.	132	50	15	20 to 6
Ogden, Utah.	132	60	12.38	16 to 10
Burlington, Vt...........	99	28	10.70	
Rutland, Vt..............	99	49½	10	12 to 6
Milwaukee, Wis..........	100	60	9	25 to 12
* London, Eng...........	80	12	4	15 to 3
* Birmingham, Eng......	80	15	9	8

* Foreign cities for comparison.

it must actually have a considerable dip in the direction of the slope of the street. If steep grades are continued across intersections, they introduce side slopes in the streets thus crossed, which are troublesome, if not dangerous, to vehicles turning the corners, especially the upper ones. Such intersections are especially objectionable in rainy weather. The storm water will fall to the lowest point, concentrating a large quantity of water at two receiving-basins, which with a broken grade could be divided between four or more basins.

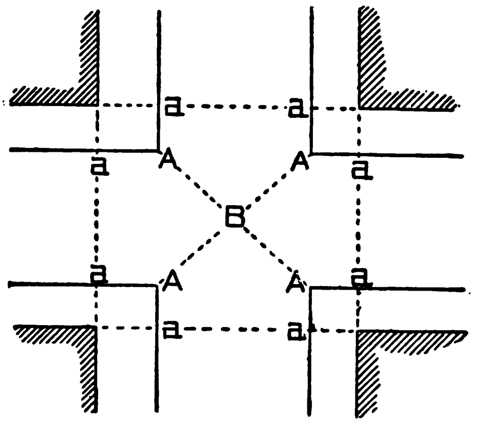


FIG. 143. ADJUSTMENT OF GRADES AT STREET-INTERSECTIONS.

752. Fig. 144 shows the arrangement of intersections on steep grades proposed by Messrs. Rudolph Hering and Andrew Rosewater for the streets of Duluth, Minn. From this it will be seen that at these intersections the grades are flattened to three per cent for the width of the roadway of the intersecting streets, and that the grade of the curbs is flattened to eight per cent for the width of the intersecting sidewalks. Grades of less amount on roadway or sidewalk are continuous. The elevation of block-corners is found by adding together the curb elevation at the points facing the block-corner, and also the sum of the widths of the two sidewalks at the corner multiplied by two and one half per cent, and dividing the whole by two. This gives an elevation equal to the average elevation of the curbs opposite the corner plus an average rise of two and one half per cent across the width of the sidewalk.

753. The instructions of the Department of Public Works of New York contain the following directions for regulating grades at street-intersections:

"In calculating the grades from the centre of the intersection to the circular corners or curb-lines, they will be established as follows: In the avenues when the ascents and descents of the cross intersecting streets exceed 1 inch in 10 feet, the grade will be cal-

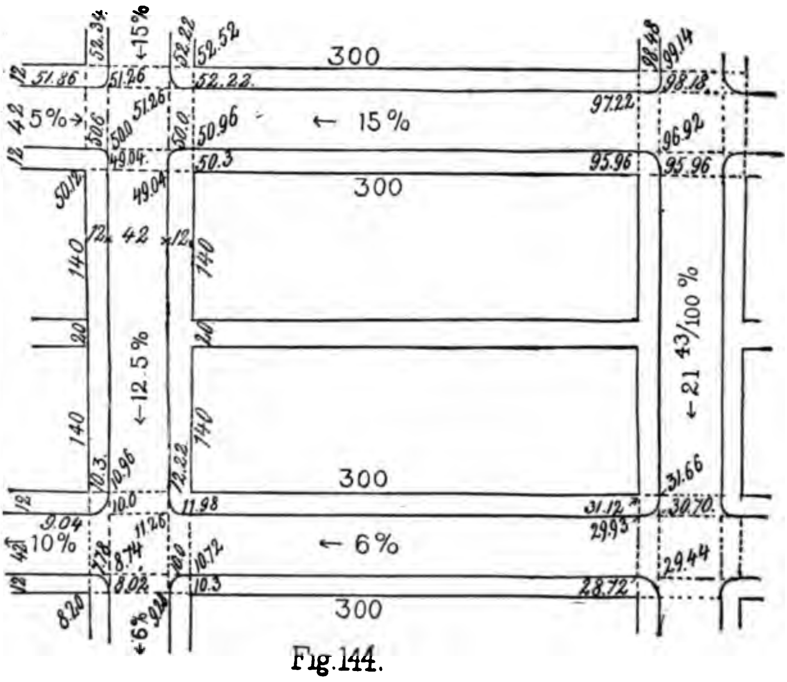


Fig. 144.

culated at 1 inch in 10 feet to the curb-line from the centre, making 6 inches difference in the curbs on opposite sides of the avenues, and the slopes up and down the avenues will be calculated according to the grade of the avenue, let the same be more or less."

"Apexes and punch-bowls to be set into the curb-line at the same height as the centre grade."

754. Accommodation summits have to be introduced between street-intersections, first in hilly localities to avoid excessive excavation, and second when the intersecting streets are level or nearly

so, for the purpose of obtaining the fall necessary for surface-drainage.

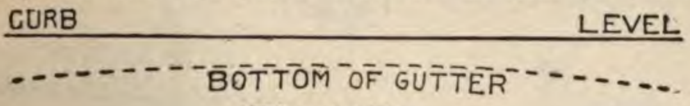
The elevation and location of these summits may be calculated as follows: Let A be the elevation of the highest corner, B the elevation of the lowest corner, D the distance from corner to corner, and R the rate of the accommodation grade. The elevation of the summit is equal to

$$\frac{D.R + A + B}{2}.$$

The distance from A or B is found by subtracting the elevation of either A or B from this quotient and dividing the result by the rate of grade. Or the summits may be located mechanically by specially prepared scales. Prepare two scales divided to correspond to the rate of grade—that is, if the rate of grade be one foot per hundred feet, then one division of the scale should equal 100 feet on the map scale. These divisions may be subdivided into tenths. One scale should read from right to left, and one from left to right.

To use the scales, place them on the map so that their figures correspond with the corner elevations; then as the scales read in opposite directions there is of course some point at which the opposite readings will be the same: this point is the location of the summits, and the figures read off the scale its elevation. If the difference in elevation of the corners is such as not to require an intermediate summit for drainage, it will be apparent as soon as the scales are placed in position.

755. Sufficient fall for surface drainage may be secured without the aid of accommodation summits, by arranging the grades as shown in Fig. 145. The curb is set level between the corners, a summit is



Fig, 145.

SHOWING CROWN IN STREET GUTTER.

formed in the gutter, and receiving basins are placed at the centre and each corner.

756. Transverse Grade.—In transverse grade the street should be level; that is, the curbs on opposite sides should be at the same level, and the street crown rise equally from each side to the centre.

But in hill-side streets this condition cannot always be fulfilled, and opposite sides of the street may differ as much as five feet; in such cases the engineer will have to use his discretion as to whether he will adopt a straight slope inclining to the lower side, thus draining the whole street by the lower gutter, or adopt the three-curb method and sod the slope of the higher side.

In the improvement of old streets with the sides at different levels much difficulty will be met, especially where shade-trees have to be spared. In such cases recognized methods have to be abandoned, and the engineer will have to adopt methods of overcoming the difficulties in accordance with the condition and necessities of each particular case.

As an example of what may be done in such cases the methods adopted by Mr. J. T. Desmond, City Engineer of Haverhill, Mass., may be cited.

In Fig. 146 is shown a street 66 feet wide, with one sidewalk

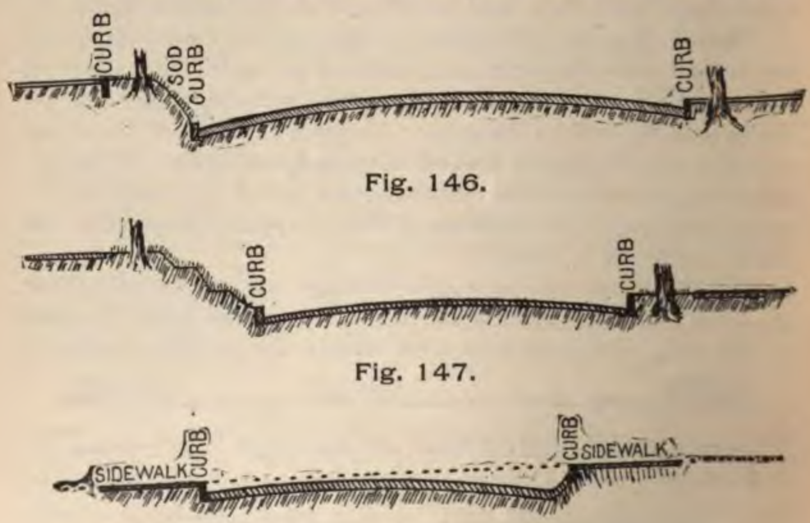


Fig. 146.

Fig. 147.

Fig. 148.

ARRANGEMENT OF STREETS WITH OPPOSITE SIDES AT DIFFERENT LEVELS.

5 feet higher than the other. In order to get a fair cross-section a third line of curbing was put in at the crest of the slope, and the

slope between the two curbs sodded. This produces a very pleasing effect.

In Fig. 147 the same conditions exist, but only two lines of curbing are used, the slope being sodded in the same manner as in the first case.

Again, it often happens that two parallel streets are laid out with sharp descending grades, and later on the city is called upon to accept a new street laid out between them. The method shown in Fig. 148 is adopted.

757. Transverse Contour.—The most suitable form of transverse contour and proper rise for each kind of pavement are given in Articles 618 and 619, Chapter XII.

758. Sub-foundation Drainage of Streets.—The sub-foundation drainage of streets cannot be effected by transverse drains, because of the liability of their disturbance by the introduction of gas, water, and other pipes.

Longitudinal drains must be entirely depended upon; they may be constructed of the same materials and in the same manner as road drains. The number of these longitudinal drains must depend upon the character of the soil: if moderately retentive, a single row of tiles or a hollow invert placed under the sewer in the centre of the street will generally be sufficient, or two rows of tiles may be employed, one placed at each curb-line; if the soil be exceedingly wet and the street very wide, four or more lines may be employed. These drains may be permitted to discharge into the sewers of the transverse streets (Fig. 149.)

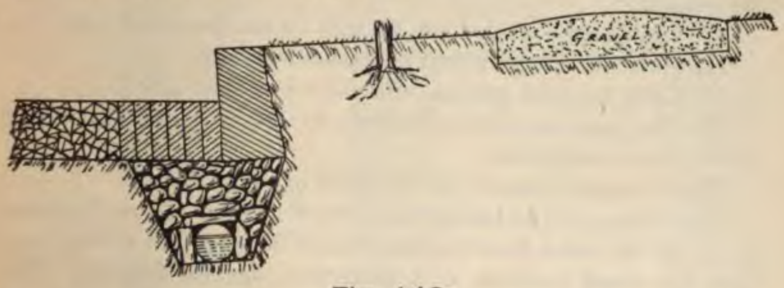


Fig. 149.

SECTION OF SUBURBAN STREET, SHOWING BROKEN-STONE ROADWAY, PAVED GUTTER, TILE-DRAIN, AND GRAVEL WALK.

759. Surface Drainage.—The removal of water falling on the street surface is provided for by collecting it in the gutters, from which it is discharged into the sewers or other channels by means of catch-basins placed at all street intersections and dips in the street grades.

760. Gutters.—The gutters must be of sufficient depth to retain all the water which reaches them and prevent its overflowing on the footpath. The depth should never be less than 6 inches, and very rarely need be more than 10 inches.

In streets paved with granite, wood, and brick, gutters are formed of the same material. When the street is paved with asphalt the gutter may be formed either of asphalt, recoated with bitumen, or with granite blocks or gutter stones. The width of this paving need not exceed 12 inches.

In streets where broken stone is used the gutters may be formed with gutter stones of granite blocks.

761. Catch-basins are of various forms, usually circular or rectangular, built of brick masonry coated with a plaster of Portland cement. Whichever form is adopted, they should fulfil the following conditions:

(1) The inlet and outlet to have sufficient capacity to receive and discharge all the water reaching the basin.

(2) Sufficient capacity below the outlet to retain all sand and road detritus, and prevent it being carried into the sewer.

(3) Trapped so as to prevent the escape of sewer-gas. (This requirement is frequently omitted, to the detriment of the health of the people.)

(4) Constructed so that the pit may be easily cleaned out.

(5) Inlet not easily choked by leaves or débris.

(6) Offer the least possible obstruction to the traffic.

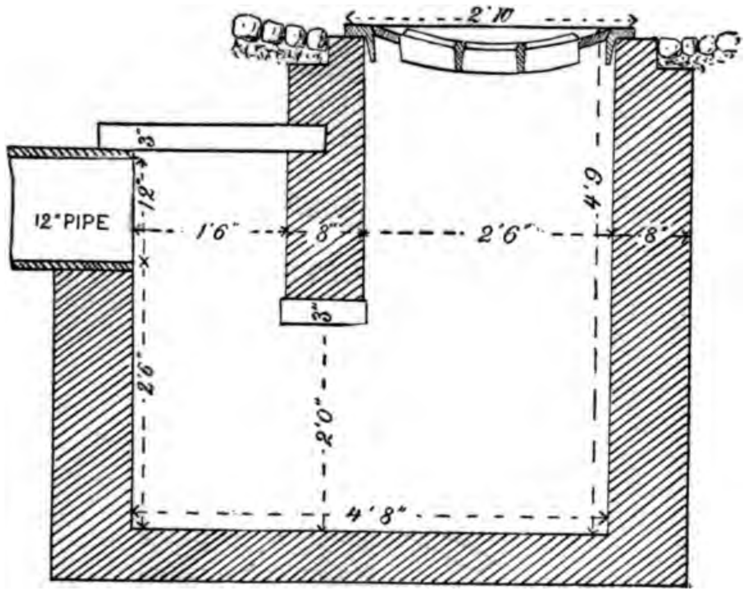
(7) The pipe connecting the basin to the sewer should be easily freed of any obstruction.

Figs. 150 to 153 show various forms of catch-basins.

The bottom of the basins should be 6 or 8 feet below the street level, and the water level in them should be from 3 to 4 feet lower than the street surface, as a protection against freezing. The capacity and number of basins will depend upon the area of surface which they drain.

In streets having level or light longitudinal grades gullies may

EXAMPLES OF CATCH-BASINS.



SECTION.

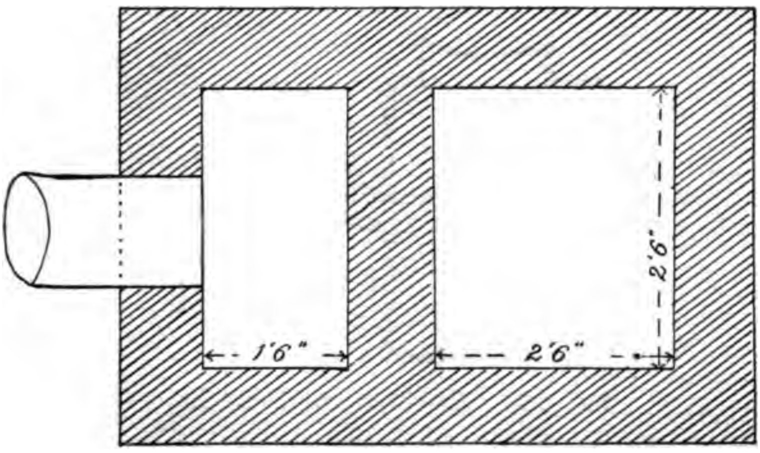


FIG. 150. PLAN.

FIG. 151. GUTTER BASIN.

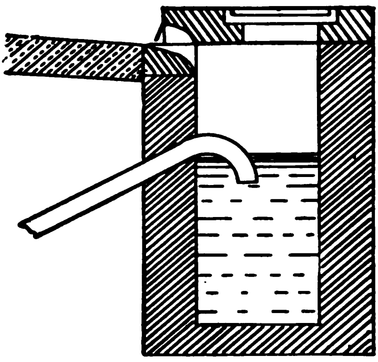


FIG. 152. CORNER BASIN.

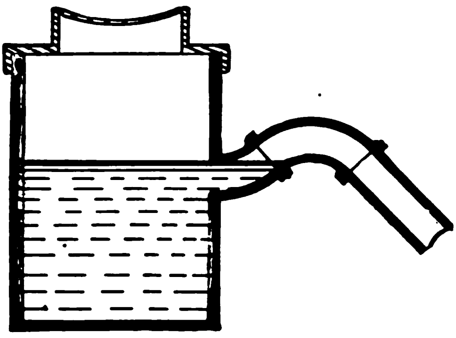


FIG. 153. EARTHENWARE BASIN.

be formed along the line of the gutter at such intervals as may be found necessary. A great variety of gully-pits and gratings have been introduced, and are illustrated in Mr. Baldwin Latham's excellent book on Sanitary Engineering.

762. Surface Drainage at Street Intersections.—The surface waters should not be carried across street intersections if it can be possibly avoided, but cases may arise where such has to be done.

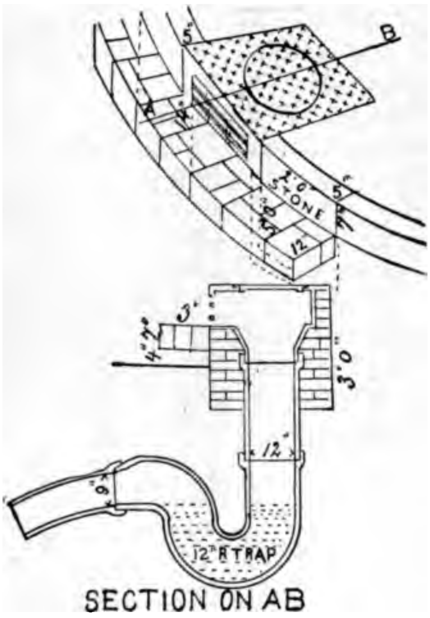


FIG. 153A. SEWER INLET WITHOUT BASIN.

Where it is necessary, it can be accomplished as shown in Figs. 154 and 155.

Waterways formed as shown in Fig. 156 should not be constructed: they are a nuisance, and an obstacle to traffic.

763. Street Lines and Monuments.—In the engineering department of every city there should be adopted and carried into effect a system of permanent street monuments, whereby the street lines may be accurately relocated at any time, even a century after the original survey was made. In the absence of such a system, it is

SURFACE-DRAINAGE AT STREET INTERSECTIONS.

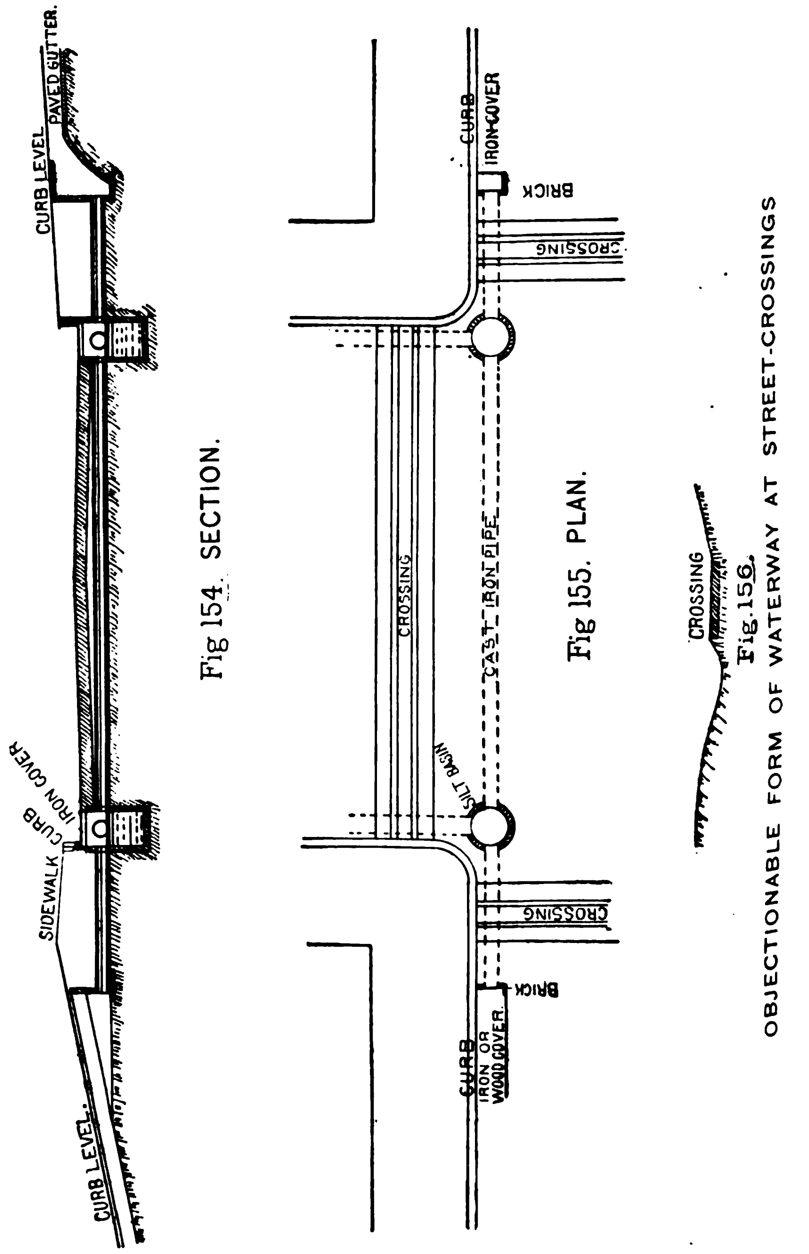


Fig 154. SECTION.

Fig 155. PLAN.

Fig.156.

OBJECTIONABLE FORM OF WATERWAY AT STREET-CROSSINGS

impossible to accurately retrace the original survey. With the improvements continually in progress old landmarks are swept away, and the reproduction of former lines is largely a cut-and-try process, involving a great deal of work which is productive of only approximate results.

The remedy lies in placing at all street corners substantial stone monuments, and protecting them by special ordinance against disturbance by persons excavating in the streets.

The monuments should not be less than 4 feet long, 12 inches square on the bottom, and 6 inches square on the top; the top surface and 4 inches of each face down from the top should be hammer-dressed. The monuments should be set with the upper surface flush with the surface of the sidewalk or a few inches below, but so placed as to be easy of access. They should be set at a fixed distance from the building line—say 5 feet. If set below the level of the footway pavement, a hole may be cut in the pavement and closed with a cast-iron frame and movable cover flush with the surface of the pavement. (See Fig. 157.)

The intersections of the lines can be accurately cut upon the top surface, or a small hole may be drilled at the intersection of the lines, filled with lead, and the point marked with a centre-punch.

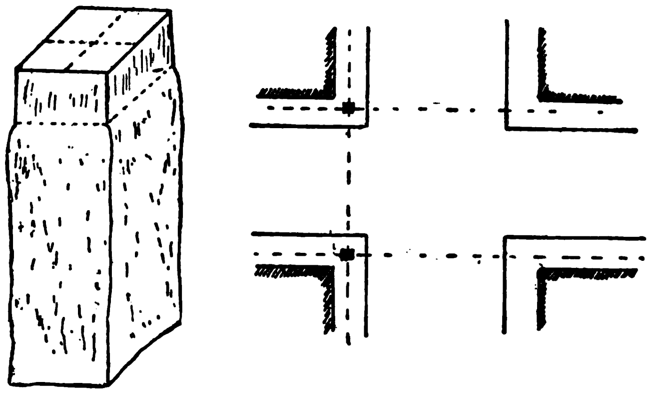


FIG. 157.—SHOWING MONUMENTS AND MANNER OF PLACING.

764. Monuments.—For defining the lines of country roads. The monuments to be of roughly dressed stone, about 5 feet long, 16 inches square at the base and tapering toward the top, with the

upper foot dressed to 8 inches square; the monument to be set in a pit 3 feet square and 4½ feet deep; the space around the stone to be filled with small stones, gravel, or earth, solidly packed in thin layers. The top of each stone marked with its diagonals, and its number cut on one of the faces which project above ground.

765. Street Profiles.—The following instructions of the Department of Public Works, New York, in regard to street profiles may be useful.

The drawings to be made on a horizontal scale of 40 feet and a vertical scale of 8 feet to the inch, and to be colored and figured as hereinafter indicated, with an explanatory legend.

For streets 60 feet wide and under there will be three profiles, one on each side and one intermediate through the centre of the street, to be shown in plan and elevation. For streets more than 60 feet wide, two additional profiles will be required, one through each curb- and gutter-line (to be drawn in plan only, not in elevation).

The established grade-line will be shown on the elevation only. Vertical heights above the high-water line will be given at least every 50 feet for the established grade-line and for the several lines of profile; the former on the elevation and the latter on the plan.

The plan will be drawn below the profile.

The colors used will be as follows:

Line of high-water (datum)	Blue
Vertical height-lines	Black
Established grade-line	Red

Natural surface as follows:

South line of streets West line of avenues	Orange
North line of streets East line of avenues	Green
North curb of streets East curb of avenues	Burnt Sienna
South curb-line of streets West curb-line of avenues	Blue
Rock to be colored with	India ink
Earth " "	Orange
Flagging " "	Blue

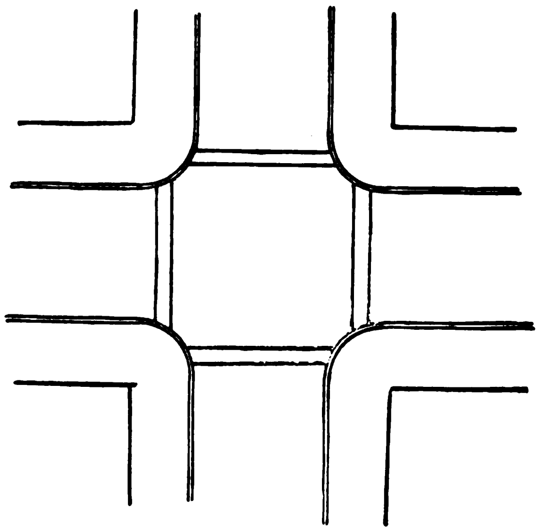


FIG. 158. TYPICAL CORNER.

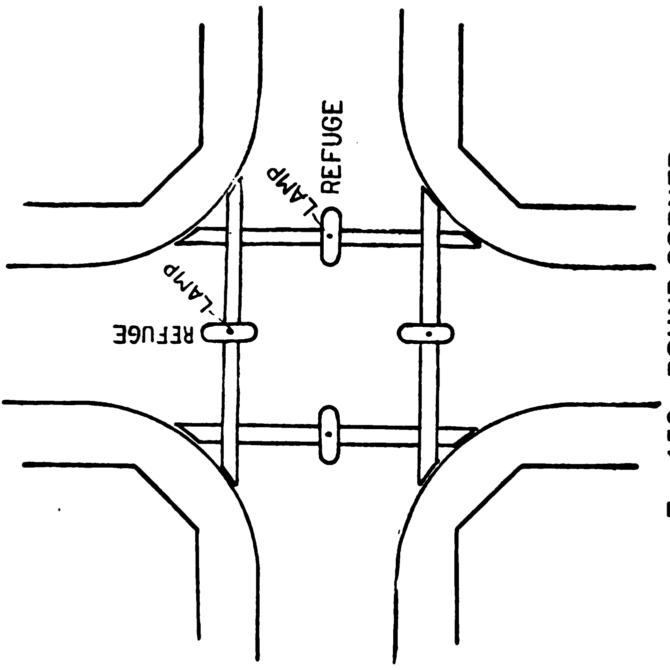


FIG. 159. ROUND CORNER.

When earth and rock occur the surveyor will be required to designate upon the original plan the outline of the intersection of the rock, when the same shall be developed by a plan parallel to and two feet below the established grade.

766. Increasing the Width of the Carriageway at Street-crossings.—Experience has proven the value of the London practice of widening the carriageway at street-corners and the providing of refuges or resting-places for pedestrians. Fig. 158 shows a typical street-corner, and Fig. 159 shows the widened corner and refuges.

Travel is always slower and somewhat congested at crossings, and the widening of the wheelway at these points expedites its movement; while the refuges, besides keeping the traffic on its proper side of the street, are of great convenience to pedestrians crossing the street. These refuges are usually 4 feet wide and about 12 feet long, and are elevated above the street surface; they are bordered by curb-stones, and in the centre is generally an ornamental lamp-post, indicating its position and carrying the street signs.

Another consideration in favor of these corners is the opportunity they present for ornamental façades, that add to the beauty of the city.

767. Street Statistics.—The following table shows the length of streets for each of fifty of the largest cities in the United States, with the amount paved and unpaved, the number of miles of streets lined with shade-trees, extent of grassed places or parking along the streets, the number of miles of streets to each square mile of area, the percentage of street area to the area of the city, and the number of population to each mile of streets for the year 1890.

TABLE LXXXIII.

Cities.	Streets.				Miles of Streets Lined with Shade Trees.	Grassed Places.		Miles of Streets to each square mile of Area.	Per cent of Street Area to City Area.	Number of Population to each mile of Streets.
	Length in miles.			Per cent of Length Paved.		Length (miles).	Average Width (feet).			
	Total.	Paved.	Graded and Curbed only.							
New York, N. Y.	575	358	45	62.26	......	......	......	14.30	16.25	2,635.31
Chicago, Ill.	2048	629	1419	30.71	1200	1300	7	12.75	15.94	537.03
Philadelphia, Pa.	1151	750	50	65.16	......	......	......	8.90	8.42	909.61
Brooklyn, N. Y.	653	375	3	57.43	183	300	5	24.68	32.72	1,234.83
St. Louis, Mo.	1061	422	40	39.77	50	30	10	17.29	19.65	425.80
Boston, Mass.	408	408	......	100.00	......	......	......	11.56	8.76	1,099.21
Baltimore, Md.	780	459	100	58.85	100	......	......	27.48	34.36	556.97
San Francisco, Cal.	342	92	190	26.90	......	......	......	22.12	28.91	874.26
Cincinnati, Ohio.	486	254	......	52.26	......	......	......	19.44	18.41	610.92
Cleveland, Ohio	462	69	129	14.94	......	......	......	18.57	23.21	565.70
Buffalo, N. Y.	372	194	......	52.15	200	350	10	9.53	10.47	687.27
New Orleans, La.	625	89	261	14.24	25	30	30	16.85	19.15	387.26
Detroit, Mich	400	147	......	36.75	......	360	15	19.43	20.97	514.69
Milwaukee, Wis.	419	72	6	17.18	349	......	......	24.65	35.01	487.99
Washington, D. C.	235	163	......	69.36	230	230	20	22.95	43.46	863.74
Newark, N. J.	186	48	138	25.81	......	......	......	10.47	11.89	977.58
Minneapolis, Minn.	800	25	4	3.13	......	400	4	15.48	23.46	205.92
Omaha, Neb	508	52	41	10.24	......	10	6	20.73	25.92	276.48
Rochester, N. Y.	240	72	72	30.00	......	......	......	15.38	14.57	557.90
St. Paul, Minn.	970	40	325	4.12	50	28	36	18.86	21.44	137.27
Denver, Col.	756	......	756	......	......	......	......	48.81	73.95	141.15
Indianapolis, Ind.	400	234	16	58.50	234	234	6	39.72	56.42	263.59
Worcester, Mass.	195	195	......	100.00	150	......	......	5.73	5.43	434.13
Toledo, Ohio.	438	60	220	13.70	70	25	12	22.21	27.76	185.92
New Haven, Conn.	140	32	......	22.86	......	......	......	18.52	21.04	580.70
Lowell, Mass	105	19	1	18.10	79	......	......	9.42	8.92	739.96
Nashville, Tenn.	251	147	......	58.57	50	150	20	29.74	28.16	303.46
Fall River, Mass.	106	2	79	1.89	......	......	......	9.68	9.17	701.87
Cambridge, Mass.	79	23	......	29.11	......	......	......	13.55	12.83	886.43
Camden, N. J.	100	31	20	31.00	50	1	20	23.04	26.18	583.13
Trenton, N. J.	100	7	50	7.00	75	5	5	25.32	28.77	574.58
Lynn, Mass	125	82	30	65.60	20	......	......	11.75	11.13	445.82
Hartford, Conn.	130	80	50	61.54	91	91	15	8.77	11.76	409.46
Evansville, Ind	136	33	52	24.26	6	1	12	30.77	40.79	373.21
Los Angeles, Cal.	800	83	76	10.38	......	80	30	28.99	32.94	62.99
Lawrence, Mass.	82	75	......	91.46	......	......	......	12.29	11.64	544.56
Hoboken, N. J.	30	17	3	56.67	9	......	......	20.41	22.42	1,454.93
Dallas, Tex.	529	25	66	4.73	15	15	2	68.88	78.27	71.96
Sioux City, Iowa	340	14	75	4.12	45	90	8	11.00	16.67	111.19
Portland, Me.	56	9	43	16.07	49	3	10	22.31	21.13	650.45
Holyoke, Mass.	50	50	......	100.00	......	12	4	12.56	14.28	712.74
Binghamton, N. Y.	80	4	70	5.00	50	50	4	7.97	7.55	437.56
Duluth, Minn.	224	35	20	15.63	......	23	10	69.35	86.69	147.83
Elmira, N. Y.	90	43	5	47.78	45	85	6	20.22	21.07	330.09
Davenport, Iowa	140	26	79	18.57	30	5	6	31.75	42.09	191.94
Canton, Ohio.	150	5	115	3.33	150	16	8	22.06	25.07	174.59
Taunton, Mass.	200	170	20	85.00	......	......	......	4.22	3.20	127.24
Lacrosse, Wis.	125	15	110	12.00	20	20	7	15.26	19.08	200.72
Newport, Ky.	30	27	3	90.00	25	2	......	25.00	31.25	830.60
Rockford, Ill.	120	31	50	25.83	60	98	5	18.84	23.55	196.53

CHAPTER XVII.

FOOTPATHS, CURBS, GUTTERS.

768. A FOOTPATH or walk is simply a road under another name, a road for pedestrians instead of one for horses and vehicles. The only difference that exists is in the degree of service required; but the conditions of construction that render a road well adapted to its object are very much the same as those required for a walk.

The effects of heavy loads such as use carriageways are not felt upon footpaths, but the destructive action of water and frost is the same in either case, and the treatment to counteract or resist these elements as far as practicable and produce permanency must be the controlling idea in each case, and should be carried out upon a common principle. It is not less essential that a walk should be well adapted to its object than that a road should be, and it is annoying to find it impassable or insecure and in want of repair when it is needed for convenience or pleasure. In point of economy there is the same advantage in constructing a footway skilfully and durably as there is in the case of a road.

769. Width.—The width of footwalks (exclusive of the space occupied by projections and shade-trees) should be ample to comfortably accommodate the number of people using them. In streets devoted entirely to commercial purposes the clear width should be at least one third the width of the carriageway; in residential and suburban streets a very pleasing result may be obtained by making the walks one half the width of the roadway and devoting the greater part to grass and shade trees.

The width adopted for sidewalks in several cities is given in Table LXXXII, page 388.

770. Cross-slope.—The surface of footpaths must be sloped so that the surface-water may readily flow to the gutters. This slope

need not be very great; $\frac{1}{8}$ inch per foot will be sufficient. A greater slope with a thin coating of ice upon it becomes dangerous to pedestrians.

771. **Foundation.**—As in the case of roadways so with footpaths, the foundation is of primary importance. Whatever material may be used for the surface, if the foundation is weak and yielding the surface will settle irregularly and become extremely objectionable, if not dangerous, to pedestrians.

772. **Surface.**—The requirements of a good covering for sidewalks are:

(1) It must be smooth but not slippery.

(2) It must absorb the minimum amount of water, so that it may dry rapidly after rain.

(3) It must not be easily abraded.

(4) It must be of a uniform quality throughout, so that it may wear evenly.

(5) It must neither scale nor flake.

(6) Its texture must be such that dust will not adhere to it.

(7) It must be durable.

773. **Materials.**—The materials used for footpaths are as follows: stone natural and artificial, wood, asphalt, brick, tar concrete, and gravel.

774. Of the natural stones, sandstone (bluestone) and granite are extensively employed.

The bluestone when well laid forms an excellent paving material. It is of compact texture, absorbs water to a very limited extent, and hence soon dries after rain; it has sufficient hardness to resist abrasion, and wears well without becoming excessively slippery. It can be obtained in flags of almost any size and thickness. As found in the quarries, the layers of stone range from 1 inch to 3 feet in thickness, the top beds being usually the thinner. The size of the blocks in superficial area varies; frequently blocks 60 feet long by 20 feet wide and 10 inches thick are lifted from the bed. The largest slab as yet brought to tide-water was 20 × 24 feet and 10 inches thick, and there are slabs used for flagging in New York 15 by 20 feet by 8 inches.

Granite, although exceedingly durable, wears very slippery and its surface has to be frequently roughened.

775. Slabs of whatever stone must be of equal thickness

throughout their entire area; the edges must be dressed true to the square for the whole thickness (edges must not be left feathered as

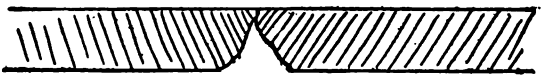


FIG. 160. IMPROPER MANNER OF DRESSING THE EDGES OF CROSSING-STONES AND FLAGSTONES.

shown in Fig. 160); and they must be solidly bedded on the foundation and the joints filled with cement-mortar.

Badly set or faultily dressed flagstones are very unpleasant to walk over, especially in rainy weather; the unevenness causes pedestrians to stumble, and rocking stones squirt dirty water over their clothes.

776. Specifications for Flagstones, (New York).—Flagstones shall be of the best quality of North River bluestone, 4 feet wide, not less than 3 inches thick, and to contain not less than 12 superficial feet. The edge shall be dressed the whole depth of the stone, so as to lay close joints, and the top shall be cut evenly, so as to leave no depressions. Flagging shall be laid in four inches of sand or clean gritty earth, and the joints closed with cement-mortar.

777. Wood has been largely used in the form of planks; it is cheap in first cost, but proves very expensive from the fact that it lasts but a comparatively short time and requires constant repair to keep it from becoming dangerous.

778. Asphalt forms an excellent footway pavement; it is durable and does not wear slippery. It is largely employed for this purpose in Europe.

The proportions of materials employed in Paris are given as follows:

Bituminous rock	1456 pounds
Bitumen	68 "
Sand	784 "

This requires about 225 pounds of coal to heat it, and one workman can prepare 3 tons of material in 12 hours.

The following table gives the number of square yards that a ton of prepared rock-asphalt will spread:

TABLE LXXXIV.

Without Grit. Square yards.	With about 25 per cent of Grit. Square yards.	Thickness. Inches.
63	80	3/8
51	65	1/2
32	40	3/4
26	33	1
16	20	1 1/2
12 1/2	16	2

A skilled workman properly assisted can lay 140 to 180 square yards in a day.

779. The life of asphalt footways may be taken at about twelve years under ordinary traffic. The concrete will remain untouched, and what is left of the asphalt may be remelted, so that a renewal is not so costly as the first expense.

Compressed-asphalt paths have lasted ten years in some of the busiest thoroughfares of London. In Leicester, uncompressed-asphalt paths have lasted fifteen years under considerable traffic.

The thickness of the asphalt should not be less than one inch.

780. Specifications for Sheet-asphalt Footway Pavements (Washington, D.C.)

Grading.—The space over which the sidewalk is to be laid will be graded to a depth of 3 inches below the finished surface of the pavement. Soft and spongy places not affording a firm foundation will be removed and good, clean gravel substituted therefor. The bed thus prepared will be thoroughly rolled and rammed to the satisfaction of the Engineer or his authorized representative.

Tree-spaces.—A space of such dimensions as may be directed by the Engineer Commissioner (usually 2 by 4 feet) will be left around each tree. Around the edges of this space will be planted a framework of Georgia pine, 2 inches in thickness and 9 inches in depth. The plank forming the rear of the framework, and which is parallel to the curb, will be firmly nailed to the other two pieces, and will be cut in such a manner that it will bind underneath the pavement to be laid, so that the top edges will be even with the pavement when completed. In the spaces between the framework and the sides of the trench coarse sand will be placed and compacted by tamping with narrow rammers especially constructed for

this purpose. These spaces will be then filled to the sub-grade of the pavement, and the tree-spaces will be filled with earth and left in a neat and clean condition.

Base.—On the bed prepared as above specified a layer of clean broken stone, of size not exceeding ¾ inch in largest dimensions, will be spread to a depth of 2¾ inches. This will be compressed by rolling and tamping to a thickness of 2 inches. On this will be poured, at a temperature of about 250 degrees Fahr., the residuum of coal-tar distillation known in the trade as No. 4 Paving Composition. About ½ gallon of this composition will be used for each square yard of pavement, and it will be poured on the base of broken stone in such manner as to thoroughly coat the stones on the surface and fill the interstices thereof.

Wearing Surface.—The cementing material of the wearing surface will be asphalt paving-cement prepared from the best quality of Trinidad asphalt, obtained from the so-called Pitch or Asphalt Lake in the island of Trinidad, and the residuum of petroleum distillation, mixed in the proportions of about six parts of refined asphalt and one part of residuum. With this paving-cement will be combined the old asphalt pavement from Pennsylvania Avenue or elsewhere, and crushed granular limestone quartz or other stone of a white color, in the following proportions:

Old pavement	69 to 76	per cent
Crushed stone	26 to 15	"
Asphalt cement as above specified	5 to 9	"
	100 100	per cent

The old pavement will be furnished by the District at the property yards near the foot of New Hampshire Avenue; the other materials will be furnished by the contractor. The crushed stone in the wearing surface will vary in size from ¼ of an inch to dust.

The asphalt pavement will be broken into pieces not exceeding 4 inches in their largest dimensions, and will then be mixed with the crushed stone in the proportion of about 4 parts of asphalt pavement to one part of crushed stone. This mixture will then be heated to a temperature of about 300 degrees Fahr. in a suitable apparatus, and thoroughly mixed and made homogeneous by stirring, special care being taken not to overheat the material or

burn the asphalt. During the progress of mixing, asphalt cement will be added in the proportion of 5 per cent to 9 per cent by weight of the mixture; the exact proportion of asphalt cement thus to be added for the purpose of enriching the old pavement will be determined by the Engineer Commissioner.

The material thus prepared will be brought to the work at a temperature of 250 degrees to 275 degrees Fahr., and will be spread on the base above specified by means of hot iron rakes to a thickness of $1\frac{1}{2}$ inches, and will then be compressed by rolling and ramming to the thickness of 1 inch. A small amount of hydraulic cement will then be spread over the surface, and the rolling will be continued until the pavement is thoroughly compressed. Care shall be taken at all times not to interfere with business or travel more than is absolutely necessary for the faithful performance of the work. During the time that travel is necessarily closed at any point the contractor shall provide temporary walks, said walk to be at all times in condition for pedestrians, and easy of access from adjoining walks. The contractor shall remove all stone, plank, brick, or other material of value from points where the sidewalks are to be laid, as the work progresses, and shall haul them to the nearest property yards, or otherwise dispose of them, as the Engineer Commissioner may desire.

Curb.—Whenever ordered the curb will be reset. Curb will be redressed by the contractor whenever ordered, for which a fair price, to be fixed by the Engineer Commissioner, will be paid.

781. Extracts from Specifications for Asphalt Footway Pavements (Paris).

Form and Dimensions of Work.—Art. 7. The width of the sidewalks for each locality will be determined by the administration, its slope by the engineer. The curb between the sidewalk and the roadway will not be included in this contract.

Art. 16. The mastic pavements will be formed of a layer of pure asphaltic mastic at least $\frac{9}{16}$ inch thick, resting on a bed of hydraulic concrete 4 inches thick which comprises a covering of hydraulic mortar at least $\frac{3}{8}$ inch thick.

Art. 17. The compressed-asphalt pavements will consist of an upper layer of compressed asphalt $1\frac{1}{2}$ to $2\frac{1}{8}$ inches thick, resting on a foundation of hydraulic lime or cement concrete 4 to 6 inches thick, covered as above with mortar, or upon an old macadam road-

way picked over and covered with a thin coat of hydraulic mortar.

Art. 21. The asphaltic mastic employed either for new or repairing old paving shall be composed of naturally impregnated rock with natural bitumen of good quality, coming exclusively from mineral rocks.

The *fictitious* bitumens extracted by the purification of the heavy oils or schists and by the distillation of coal, also the so-called fatty bitumens, and all other analogous products shall be rigorously proscribed.

The rock employed after being reduced to powder will be melted with a sufficient quantity of purified natural bitumen to form a mastic which, when cold, presents a homologous mass slightly elastic and which does not soften under a hot sun. This mastic shall be moulded into blocks. There may also be used blocks of bituminous mastic with a base of slates manufactured by the process of M. Sebille.

Art. 22. The contractor shall be bound to employ under the orders of the engineers upon each public way the bituminous mastic above described.

The mastic shall be formed of a mixture of natural bitumen, in the proportion of one twelfth of its weight at most, and the calcareous asphalt rocks of Seyssel, Seyssel-Forens, Pyrimont or Volants, of Val de Travers or Lobsan, or others deemed equivalents by the engineers.

The mastic having a base of slate of M. Sebille will be formed of a mixture of bitumen described in Art. 23 following, and of powdered red or blue slate of Ardennes, powdered chalk of Mendon or of Nanterre, and of silica from the basin of Paris, in the following proportions by weight:

Refined mineral bitumen	30 parts
Ground slate	35 "
Powdered chalk	10 "
Silica, ground and sifted	25 "
	100 parts

Art. 23. The bitumen shall come as much as possible from the weighings of bituminous sandstone or the asphaltic rock of Maestu, and in their default from the dry pitch of Trinidad, perfectly puri-

fied. It ought to be viscid at the ordinary temperature, never brittle or liquid; drawn into threads it should lengthen and only break in very fine points.

Art. 24. The rock employed should be calcareous, soft, with fine grain, texture fairly compact, regularly impregnated with bitumen so as not to show black and white spots; it should be of a brown color; heated to 122 to 140 degrees Fahr. it should soften and break on being torn. Care must be taken for the area in asphalt to choose only such pieces as are of the most even grain and richest impregnation. The rock of Lobsan, however, should not be employed alone in the asphalt roadways; it ought to be mixed with other rocks less fat, in proportions which will be determined by the engineer according to the composition of the other rocks. It should contain at least 7 per cent of bitumen and at the most 93 per cent of lime; its change into mastic must not require more than 9 per cent of bitumen.

Art. 25. The materials entering into the composition of the pavements are the mastics described in Art. 22; pure gravel grit and natural bitumen to assist the melting. These materials ought to be generally employed in the following proportions by weight:

Foot-pavements with a base of asphalt	Asphaltic mastic......	100
	Bitumen............	6
	Grit....	60
Foot-pavements with a base of slate....	Asphaltic mastic......	100
	Bitumen..............	7
	Gravel.....	50

Art. 26. One month before the award of this contract the competitors must deposit at the office of the works in Paris samples of, 1st, a block of the mastic described above; 2d, specimens of the asphaltic rocks and the natural bitumens they intend to use; 3d, a note indicating the elements of the composition of the mastics, and proportions of the various rocks that they intend to employ in the composition of the asphaltic areas. The blocks and specimens of rocks and bitumen to have the trade-marks of the works from whence they came and the signatures of the competitors.

The necessary certificates to compete for the contract will not be delivered till after the examination and acceptance by the engineers of the specimens deposited. During all the term of this

contract the contractor can only use materials exactly similar to the specimens deposited.

Art. 27 provides for continuous inspection of the contractor's works, and the right to compel the contractor to manufacture the mastics in the depots belonging to the city.

Art. 31. The lime employed is to be hydraulic lime in powder. It must be brought onto the works in sealed bags marked with the name of the maker. Only the lime and cement designated in the specifications for the construction and repair of sewers will be allowed.

Art. 32. The broken flint must pass through a ring of $2\frac{1}{2}$ inches and be at least $\frac{3}{4}$ inch thick. It must be free from all earthy matters and washed clean.

Art. 33. The sand shall be dredged from the Seine and well cleansed from all foreign matter; it shall be screened from all grains larger than $\frac{3}{8}$ inch for the mortars or $\frac{3}{16}$ inch for grit for the mastic pavements. The grit for this last purpose shall be perfectly washed and dried before use.

Art. 34. The mortar of hydraulic lime shall be composed of 5 parts of sand and 2 parts of lime, by volume, furnished in powder; the mixture shall be directly reduced to a paste by adding the quantity of water exactly required to reduce it to the consistency of plastic clay.

The cement-mortar shall be composed of 1 part of hydraulic cement of Bourgogne or Portland cement of Boulogne and 3 parts of sand; the sand and cement shall be thoroughly mixed before the addition of any water. All mortar which shall have set shall be rejected.

Art. 35. The beton shall be composed ordinarily of 2 parts in volume of mortar and 3 of stone. The mixture, made either by rake or cylinder, must be perfectly uniform.

All beton not used at the time of making shall be rejected.

Art. 36. The bed of beton for the foundation of the sidewalks shall be well rammed and compressed, and must at least commence to set and dry before receiving mastic or asphalt. The beton shall in addition be covered with a layer of mortar $\frac{3}{8}$ inch thick.

The gravel for foundation shall pass in every direction through a ring 2 inches in diameter. It must be perfectly compressed and sprinkled with lime-grout. This foundation shall have commenced

to set before the application of the mastic, and shall be covered with a layer of mortar like the beton.

Art. 39. The ground upon which the mastic pavement is to be placed shall always be previously rammed, watered, and crowned with care. When it is thus made solid the contractor shall spread over it the foundation layer, formed according to the orders of the engineer—either a bed of beton or of sand covered by a layer of mortar, or a bed of sand impregnated with goudron 2¾ inches thick, or any other foundation prescribed by the engineer.

In all cases the pavement shall not be laid till the foundation has attained the firmness desired and becomes quite dry.

The contractor must conform to the following orders for the manufacture of the mastic to be used for pavements:

The mastic shall be prepared and cast in one or more manufactories belonging to the contractor, and which shall always remain open to the inspection of the engineers and their agents.

The contractor shall besides establish in the manufacturing depots, both of asphalt and mastic, offices exclusively for the agents of the administration set apart for the inspection of the composition of these materials. These materials shall not be admitted into the works without a carter's delivery note given by the inspector, setting forth that they have been manufactured in accordance with the specifications.

There shall only be allowed in the works blocks of mastic conforming to the samples deposited and accepted before the award, and bearing the trade-mark, or the old mastics from the walks and streets of Paris. All other bituminous matters, resinous or fatty, found in the works by the agents of the administration will subject the contractor to a deduction of $100 for each time they are found.

To assure the execution of these conditions the contractor must not have in any manufactory, under the same penalty, any other blocks than those which should be prepared in his works, and the old mastics that have been taken up.

The use of the old mastic is authorized in the works of the city in the proportion of one half with the new; the pieces of the old sidewalks having been perfectly cleaned with great care, and regenerated by the addition of new purified bitumen and a sufficient

quantity of powered asphalt to render the old mastic, when melted, of the aspect and consistence of the blocks in fusion.

This mastic shall be melted in hermetically closed boilers, on wheels of a model approved by the administration, and arranged so that the material can be conveyed from the factory to the place to be used, ready to be employed.

For melting, the mastic is broken into pieces 4 inches cube, then the bitumen is melted and the mastic added little by little.

The grit must not be thrown into the boiler till the mastic is completely dissolved.

During the whole time of the operation the matter must be stirred up almost constantly, so that the combination shall be well made and the mastic not burned.

The mastic being well melted and perfectly homogeneous, it shall be run out in bands of about five feet wide, spread with a wooden float, and levelled with a strike, so as to present neither fissure nor joint. The mastic must be perfectly level, and matched exactly with the curbs, etc., against which it is laid. For this purpose the parts of the curbs, flags, etc., which will be in contact with the bitumen shall be previously warmed and goudroned.

Art. 40. Upon the soil, well shaped and rammed, shall be placed a bed of concrete, covered with a layer of mortar.

The asphaltic rock, conforming to article 24, broken down or decrepitated by heat, shall be raised to a uniform temperature of from 248 to 266 degrees Fahr., and carried to the place of employment in vehicles that will prevent as much as possible the loss of heat. It must be completely freed from the the water it contains. The use of old compressed asphalt, taken from old roads, is authorized for mixture with new asphalt, in the proportion of one quarter of old compressed to three quarters of new rock, provided that the old shall be cleansed with great care before grinding and mixing with the new.

Asphalt shall not be put on the concrete foundation until it is perfectly set and dry.

The powder shall be spread with a thickness about two fifths more than the finished thickness, levelled with great care, and then rammed, at first carefully, then gradually augmenting the force by means of cast-iron *pilons* heated to the proper temperature in portable furnaces. In specially exceptional cases the compression

may also, with the written permission of the engineer, be accomplished by means of rollers.

In every case, after the pilonnage is finished, the surface shall be smoothed by means of a heated iron (*lissoir*).

The road shall not be open to traffic until it is quite cool.

Art. 43. In conformity with the contract price, stipulated hereafter, diminished by the rebate of the awarded contract, the contractor must make the necessary repairs to all asphaltic mastic footpaths and areas, furnishing the necessary labor and materials, so that they shall be kept in proper condition. He must each year of the duration of the contract completely relay, in new material, at least the fifteenth part of the surfaces of mastic and compressed asphalt. The surfaces in mastic must be properly plane and regular, presenting neither hollows nor projections of more than $\frac{3}{8}$ inch in a circle whose radius is $3\frac{1}{4}$ feet. These surfaces must be free from fissures.

Art. 45. As the works in asphalt or mastic are accepted by the engineer they will pass into the charge of the contractor, who will receive for the maintenance the price stipulated, commencing from the first of January next following their acceptance, whatever may be the date of said acceptance.

In the last nine months of the year instalments may be paid on the contract when the engineers recognize that the conditions have been loyally carried out. The accumulated sums of these instalments must not exceed four fifths of the amount of the sums which shall be due after the time has expired. The balance of the contract price of the year will be paid in the course of the first quarter of the following year.

Art. 49. All damages in the bituminous surface, such as fissures or cracks of at least $\frac{1}{16}$ inch in width, or parting from the curbs $\frac{3}{16}$ inch in width, any lifting up or breaking away of the mastic for at least $\frac{3}{16}$ inch in depth, depressions in consequence of settlement of at least $\frac{3}{8}$ inch in depth under a straight-edge, $3\frac{1}{4}$ feet long, will subject the contractor to a deduction of 3 francs (58 cents) per day when the repairs shall not have been done within 48 hours after notice given by the engineer.

Art. 51. During the continuance of frost, and during the first month after the commencement of the thaw, there shall be no repairs to the pavements maintained by the contractor, and the in-

spection for defects shall be suspended; but the contractor shall fill with sand and gravel any holes in these pavements within 24 hours after notification by the engineer, under a penalty of 10 francs ($1.93) for each day they remain unfilled. He may be authorized, in exceptional cases, to fill the holes with broken flint or melted bitumen, but must replace the flint or bitumen with asphalt as soon as the weather permits. It must be so arranged that the main repairs, intended to re-establish the normal outline of the roadways, are effected from May 1st to November 1st.

Art. 65. When a workman leaves one of the districts of the works under the municipal service, he must have a certificate from the contractor showing the cause for which he left.

This certificate shall be submitted at once to the engineer, who shall be at liberty to refuse the right of employing the said workman, without the contractor deriving therefrom any excuse for not furnishing, when requisite, the number of workmen required. In default of a certificate, the workman cannot be admitted, except on the written order of the engineer.

782. Compressed-asphalt Tile-pavement.—The success attending the introduction of compressed-asphalt blocks for light-traffic streets has led to the use of the same composition under the name of "compressed-asphalt tiles" for sidewalk pavements. These tiles can be made of any form and thickness required. The dimensions found most suitable are 8 × 8 inches square and $2\frac{1}{2}$ inches thick. In this form they have been laid in large quantities during the last seven years and appear to have given satisfaction.

782. Specifications for Laying Compressed-asphalt-tile Sidewalk-pavements.

(1) The tiles will be laid on a foundation of gravel and sand thoroughly compacted by ramming and rolling.

(2) The space over which the pavement is to be laid shall be excavated to the depth of ten (10) inches below the top surface of the finished pavement. Any perishable or other objectionable material found below this depth must be removed and the space filled with clean gravel or sand; the surface of the foundation so prepared shall be thoroughly compacted by ramming and rolling.

(3) The foundation for the tiles will be formed of a bed of fine bank gravel four inches in depth when compacted, screened from all pebbles measuring more than one and one-half inches. Upon

the gravel there shall be laid a bed of fine, sharp sand, washed and dried, four inches in thickness. The foundation of sand and gravel shall then be thoroughly consolidated by ramming and rolling, care being taken to preserve the surface of the sand parallel to the slope required for the finished surface of the pavement. (The hand-rammers shall weigh not less than 25 lbs., and the rollers not less than 300 lbs.)

(4) The tiles shall be laid at right angles to the street line, and their surface when finished must be even with the top of the curb and shall have the required slope.

The tiles shall be laid by the pavers standing or kneeling upon the tiles already laid, and not upon the sand-bed.

Each course of tiles must be of uniform width and depth, and so laid that all longitudinal joints shall be broken by a lap of at least two inches.

Each course shall be driven against the course preceding it by a maul so as to make tight joints.

When thus laid the tiles will be covered with clean, fine, dry sand, free from loam or earthy matter, and screened through a sieve having not less than 20 meshes to the inch.

(5) The tiles shall then be carefully rammed by placing a plank over several courses and striking the plank with a rammer weighing not less than 25 lbs.

The ramming shall be continued until the tiles reach a firm, unyielding bed and present a uniform surface with the required grade. Any lack of uniformity in the surface must be corrected by taking up the tiles and relaying them.

When the ramming is completed a thin layer of fine dry sand shall be spread over the surface and swept into the joints.

784. Brick.—Brick of suitable quality well and carefully laid on a concrete foundation makes an excellent footway pavement for residential and suburban streets of large cities, and also for the main streets of the smaller towns. The bricks should be a good quality of paving-brick (ordinary building-brick are unsuitable; they soon wear out and are easily broken). The bricks should be laid in parallel rows on their edges, with their length at right angles to the axis of the path. They should be set in cement-mortar and the joints filled flush and made as close as possible.

785. Specifications for Brick Walks (Washington, D. C.).—Brick pavements will be laid on a foundation of gravel and sand; and the bricks will be furnished by the District, delivered on the line of the work. The space over which the pavement is to be laid will be excavated to the depth of 10 inches below the top surface of the proposed pavement when thoroughly compacted by rolling or ramming. Any objectionable or unsuitable material below the bed will be removed, and the space filled with clean gravel or sand. Care must be taken in excavating to preserve the proper slope parallel with the surface. Upon the foundation will be laid a bed of fine sandy bank gravel, 4 inches in depth when compacted, screened from all pebbles measuring more than 1½ inches in their largest dimensions, and thoroughly rolled or rammed. Upon this will be laid a bed of fine, clean, sharp sand, 4 inches in thickness, to serve as a bed for the bricks, which will be laid directly upon and imbedded in it with close joints. Special care will be observed to make the surface of this bed of sand parallel to the surface of the pavement when finished. The bricks must be laid by the pavers standing or kneeling upon the bricks already laid, and not upon the bed of sand.

The bricks are to be laid at right angles with the line of the street, or in herring-bone style, as may be directed by the Engineer Commissioner, and even with the top of the curb when rammed; each course to be of bricks of a uniform width and depth, and so laid that all longitudinal joints shall be broken by a lap of at least 2 inches. When thus laid the bricks will be immediately covered with clean, fine, dry sand, free from loam or earthy matter, and screened through a sieve or screen having not less than 20 meshes to the inch. The bricks will then be carefully rammed by placing a plank over several courses and ramming the plank with a heavy hammer. The ramming will be continued until the bricks reach a firm, unyielding bed and present a uniform surface, with proper grade and slope. Any lack of uniformity in the surface must be corrected by taking up and relaying. When the ramming is complete a sufficient amount of fine, dry sand, as above described, will be spread over the surface and swept or raked into the joints.

Rectangular spaces, 7 by 3 feet in dimensions, will be left unpaved around trees where already planted, and at intervals of 25 feet between centres adjacent to the curb on streets where

trees have not been planted. When so ordered a continuous tree space of 4 feet wide will be left unpaved adjacent to the curb. Edges of brick pavements when not abutting against the curb will be finished with a continuous row of brick on edge.

Quality of Brick.—Sidewalk paving-brick to be of dimensions $8\frac{1}{4}$ by 4 by $2\frac{1}{4}$ inches, hard-burned throughout, of dark red color, without flaws or cracks, and square and true on the edges. Specimens required.

Arch-bricks to be of dimensions $8\frac{1}{4}$ by 4, by $2\frac{1}{4}$ inches, hard-burned throughout, sound, and of true and regular shape. All to conform to the samples submitted with the proposals. No swelled brick or soft or salmon brick will be allowed. Specimens required.

In relaying brick sidewalks the existing sidewalks will be taken up and the bricks carefully piled and preserved. The bed will then be prepared in the same manner as prescribed for new brick walks. After the bed is prepared the old brick will be cleaned of all adhering materials so that they can be relaid with close joints, when they will be laid as prescribed for new brick pavements.

786. Artificial Stone.—Artificial stone is being extensively used as a footway-paving material both in Europe and America. Its manufacture is the subject of several patents, and numerous kinds are to be had in the market. When manufactured of first-class materials and laid in a substantial manner, with proper provision against the action of frost, artificial stone forms a durable, agreeable, and inexpensive pavement.

The varieties most extensively used in the United States are known by the names of "granolithic," "monolithic," "ferrolithic," "kosmocrete," "metalithic," etc.

The process of manufacture is practically the same for all kinds, the difference being in the materials employed; the usual ingredients are Portland cement, sand, gravel, and crushed stone.

787. Artificial stone for footway pavements is formed in two ways, viz., in blocks manufactured at a factory and brought on the ground and laid in the same manner as natural stone, or the raw materials are brought upon the work, prepared and laid in place, blocks being formed by the use of board moulds.

788. The manner of laying is practically the same for all kinds. The area to be paved is excavated to a minimum depth of 8 inches, and to such greater depths as the nature of the ground may require

to secure a solid foundation. The surface of the ground so exposed is well compacted by ramming, and a layer of gravel, ashes, clinker, or other suitable material is spread and consolidated; on this is placed the concrete wearing surface, usually 4 inches thick. As a protection against the lifting effects of frost the concrete is laid in squares, rectangles, or other forms having areas ranging from 6 to 30 square feet, strips of wood being employed to form moulds in which the concrete is placed. After the concrete is set these strips are removed, leaving joints about half an inch wide between the blocks. Under some patents these joints are filled with cement, under others with tarred paper, and in some cases they are left open.

789. Good artificial stone is far superior to any other material for footway pavements. It is of a uniform temper and homogeneous throughout, and consequently its wear is more uniform than that of natural stones. It is practically non-absorbent, and consequently dries very quickly after rain.

790. The quality of the cement is an important point in the manufacture of artificial stone. A cement of improper quality will cause cracking. The characteristics of good cement are treated of in Chapter IX.

New Portland cement when spread and subjected to a process of aeration will increase in bulk at least 5 per cent. If stones are manufactured with such cement they will blow and crack. Cement increases in strength with age, and therefore stone manufactured with it will also increase in the same ratio; and again, Dykerhoff has shown that slow-setting cement had an average expansive power of .0734 per cent, and quick-setting .2019 per cent, over a period of twelve months.

791. The following detailed particulars for the laying of concrete footway pavements is taken from "Roads, Streets, and Pavements," by Q. A. Gillmore:

"Concrete footpaths should be laid upon a form of well-compacted sand, or fine gravel, or a mixture of sand, gravel, and loam. The natural soil, if sufficiently porous to provide thorough subdrainage, will answer.

"It is not usual to attempt to guard entirely against the lifting effects of frost, but to provide for it by laying the concrete in squares or rectangles, each containing from 12 to 16 superficial feet, which will yield to upheaval individually like flagging stones,

without breaking and without producing extensive disturbance in the general surface.

"When a case arises, however, where it is deemed necessary to prevent any movement whatever, it can be done by underlaying the pavement with a bed of broken stone, or a mixture of broken stone and gravel, or with ordinary pit-gravel containing just enough of detritus and loam to bind it together. In high latitudes this bed should be 1 foot and upwards in thickness, and should be so thoroughly subdrained that it will always be free from standing water. It is formed in the usual manner of making broken-stone or gravel roads already described, and finished off on top with a layer of sand or fine gravel, about one inch in depth, for the concrete to rest upon.

"The concrete should not be less than 3½ and need rarely exceed 4 to 4½ inches in thickness. The upper surface to the depth of ½ inch should be composed of hydraulic cement and sand only. Portland cement is best for this top layer. For the rest, any natural American cement of standard quality will answer. The following proportions are recommended for this bottom layer:

Rosendale or other American cement	1	measure
Clean, sharp sand	2½	"
Stone and gravel	5	"

"It is mixed from time to time as required for use, and is compacted with an iron-shod rammer in a single layer to a thickness less by ½ inch than that of the required pavement. As soon as this is done and before the cement has had time to set, the surface is roughened by scratching, and the top layer, composed of 1 volume of Portland cement and 2 to 2½ volumes of clean, fine sand, is spread over it to a uniform thickness of about 1¼ inches and then compacted by rather light blows with an iron-shod rammer. By this means its thickness is diminished to ½ an inch. It is then smoothed off and polished with a mason's trowel and covered up with hay, grass, or other suitable material to protect it from the rays of the sun and prevent its drying too rapidly.

"It should be kept damp and thus protected for at least ten days, and longer if circumstances will permit; and even after it is open for travel a layer of damp sand should be kept upon it for two or three weeks, to prevent wear while tender.

"At the end of one month from the date of laying, the Portland-cement mixture forming the top surface will have attained nearly one half its ultimate strength and hardness, and may then be subjected to use by foot-passengers without injury.

"The rammers for compacting the concrete should weigh from 15 to 20 pounds, those used on the surface layer from 10 to 12 pounds. They are made by attaching rectangular blocks of hard wood shod with iron to wood handles about three feet long, and are plied in an upright position. Certain precautions are necessary in mixing and ramming the materials in order to secure the best results. Especial care should be taken to avoid the use of too much water in the manipulation. The mass of concrete, when ready for use, should appear quite incoherent and not wet and plastic, containing water, however, in such quantities that a thorough ramming with repeated though not hard blows will produce a thin film of moisture upon the surface under the rammer, without causing in the mass a gelatinous or quicksand motion."

792. One cubic yard of concrete laid 3 inches thick will cover 10 square yards of surface. For the wearing surface the cement and sand are mixed in equal parts.

793. Covering Capacity of Cement in Square Feet.

	Thickness in Inches.		
	1"	¾"	½"
1 bbl. of Portland cement will cover...	36	48	72
1 bbl. cement and 1 bbl. sand will cover..........	66	84	132
1 bbl. cement and 2 bbls. sand will cover.........	96	124	192

794. Wear.—As regards the wear of artificial stones, the following notes from London may be interesting: "Artificial stones have now been used by almost every Vestry and District Board in the metropolis, and from testimonials it would appear that they have given satisfaction."

A portion of Victoria stone was laid in Piccadilly in 1872, and is said to be in good condition still, having been in use nineteen years.

In 1869 the approach to Blackfriars Bridge was paved with Victoria stone, and six years later, Mr. Carr, the engineer, said, the surface was perfect and the wear decidedly less than York stone contiguous. This stone has also been laid in Holburn, where the

traffic is estimated at 88,355 persons daily, and Aldgate High Street, where the traffic is estimated at 79,048 daily. Portions of the stone were taken up after five years, and the wear was found to be so slight as to be scarcely measurable.

Imperial stone has also been largely used throughout the metropolis, and appears to have given every satisfaction.

Several varieties of good stone are in the market; as examples the following may be cited:

	Cost per yard laid.	Tensile Strain in pounds per square inch.	Compressive Strain, lbs. per square inch.	Thickness in inches.	Weight in lbs. per cubic ft.
Imperial	$1.35	980	9,492	$2\frac{3}{16}$	
Croft	1.32		9,394	2	132
Victoria	1.38-1.44	1,125	8,321	2	144
Granolithic	1.31	1,000	8,500	2	
Jones annealed....	1.30	510* 1,500†		$2\frac{1}{4}$	150
York (natural).....	1.56		5,714	3	156

* 1 month old. † 12 months old.

The following tests were made by Mr. W. Sykes, Surveyor, Fulham, London, to find the comparative wear of artificial and natural stones. The stones were of equal superficial area, all bound together with cord, so that each stone found its own bed when rubbed on York stone with sand and water.

	York.	Imperial.	Victoria.	Croft.
Thickness before being rubbed..	$2\frac{1}{4}$ in.	$2\frac{9}{48}$ in.	$2\frac{3}{48}$ in.	$2\frac{1}{48}$ in.
First hour....................	$2\frac{3}{24}$	$2\frac{4}{24}$	$2\frac{1}{24}$	$2\frac{1}{48}$
Second hour.	$2\frac{3}{48}$	$2\frac{7}{48}$	$2\frac{1}{48}$	2
Third hour....................	$2\frac{1}{48}$	$2\frac{6}{48}$	2	$1\frac{23}{24}$
Total wear....................	$\frac{11}{48}$	$\frac{3}{48}$	$\frac{3}{48}$	$\frac{3}{48}$

From these figures it will be seen that the total wear in the three hours was for York $\frac{11}{48}$ of an inch, Imperial $\frac{3}{48}$, Victoria $\frac{3}{48}$, Croft $\frac{3}{48}$.

This experiment is interesting as showing that the wear of York was $\frac{1}{8}$ inch more than that of artificial stone; also that the

Imperial, Victoria, and Croft wore equally, and would therefore be of the same degree of hardness.

The York stone referred to above is a sandstone composed chiefly of silica cemented together by a matrix of lime, clay, etc.; it is of very unequal quality, being either exceedingly hard or quite soft; it is also very absorptive, and is liable to laminate under frost.

795. Specifications for Concrete Footwalks.—*Preparation of Foundation.*—The natural-soil surface shall be regulated and graded to a depth of 8 inches below the level of the finished surface of the walk; perishable and objectionable material shall be removed. On the surface so graded spread a layer of clean gravel (broken bricks or steam ashes) to such depth as will give on thorough consolidation a thickness of 4 inches. On the foundation so prepared the concrete shall be placed; moulds formed of ½-inch boards shall be placed at every 6 feet and adjusted to the required grade and pitch. The concrete shall be placed in these moulds and thoroughly rammed. After the concrete has set, its surface will be covered with the wearing coat, one inch thick, the surface of which shall be neatly trowelled to the required grade.

Traffic shall be kept off for a period of 15 days or until the surface is thoroughly set.

All vault-covers, stop-cock boxes, etc., shall be adjusted to the required grade, and the concrete shall make neat and close connection with their surface.

The concrete shall be composed of:

American hydraulic cement	1 part
Broken stone	7 parts
Gravel and sand	8 "

The wearing surface will be composed of:

Portland cement	1 part
Sharp sand	1 "

796. Specifications for Artificial-stone Footpaths (Washington, D. C.).—The contractor shall remove all stone, plank, bricks, or other materials of value from points where the sidewalk is to be laid as the work progresses, and shall haul them to the nearest property yard, or otherwise dispose of them as the Engineer Comis-

sioner may direct. Care shall be taken at all times not to interfere with business or travel more than is absolutely necessary for the faithful performance of the work. No more than 100 feet shall be closed to travel at any one time, nor remain closed for a longer time than three days, and free ingress and egress from the streets to all stores and hallways shall be provided for at all times; and during the time that travel is closed at any point the contractor shall provide a temporary walk, said walk to be at all times in condition, perfectly safe for pedestrians, and easy of access from adjoining walks.

The contractor shall make such cutting and filling as may be necessary to bring the foundation to the subgrade, 6 inches below the established grade of the sidewalk.

Whenever the Engineer Commissioner or inspector may deem it necessary, the foundation shall be consolidated by wetting, rolling, or ramming, to give it proper stability. Upon the foundation thus prepared there shall first be laid 3 inches of concrete, composed of one part natural hydraulic cement, two and one half parts sand, and five parts broken stone, which shall be rammed in place to the satisfaction of the Engineer Commissioner. On this concrete bed shall be laid three quarters of an inch of mortar, composed of four measures of clean, sharp sand and one of Portland cement, which shall be put in dry as possible, and rammed in place with an iron rammer weighing at least 25 pounds. Upon the foundation thus prepared shall be laid square blocks or tiles $2\frac{1}{2}$ inches thick, measuring 18 inches on a side. They shall be laid so as to present a true surface on top and conform to the exact grade of the sidewalk. A thin grouting of pure Portland cement of the best quality shall be spread over the surface and carefully swept into the joints. All superfluous grouting shall be cleaned off, and the walk shall be protected with plank or otherwise until the cement has thoroughly set.

Driveways crossing the footpath shall be laid with granite or asphalt blocks, as may be directed by the Engineer Commissioner. The tiles shall be $2\frac{1}{2}$ inches thick. The lower $1\frac{3}{4}$ inches to be composed of one part Portland cement (equal to that specified in current District of Columbia specifications) and two parts of clean, sharp sand, thoroughly mixed, using as small a quantity of water as possible, and carefully rammed into the moulds. The upper

one-half inch and the sides for one-half inch shall be composed of one part Portland cement, of same quality as above, and one part clean, sharp sand.

The surface shall be finished smooth but not polished. The tiles, when being seasoned, shall be kept wet for the first five days. No tiles shall be used on the work unless guaranteed by the contractor to be at least thirty days old. Unless otherwise ordered, the edge of the sidewalk shall be finished with plastering of Portland cement and sand of equal parts. The blocks will be laid with the edges perpendicular to or parallel with the line of the street, as may be ordered by the Engineer Commissioner.

Cement Inspection.—No cement shall be used on this work unless approved by the Engineer Commissioner. For this purpose he shall be entitled to take one-half pound from each package. The decision of the Engineer Commissioner shall be final in all cases, and no cement condemned by him shall be used on the work for any purpose whatever. All cements will be required to pass the tests specified in current District of Columbia specifications.

All surplus material and refuse shall be removed by the contractor twenty-four hours after the completion of the work; and in case of neglect on the part of the contractor to do so within the specified time, the Engineer Commissioner shall have the same removed, and the expense thereof shall be charged to the contractor and deducted from his estimates. Whenever any private driveway crosses the sidewalk, the plan thereof shall be modified as the Engineer Commissioner shall direct.

No material of any kind shall be used until it has been examined and approved by the Engineer Commissioner, who shall have full power to condemn the work or material not in accordance with the specifications, and to require the contractor to remove any work or material so condemned, and at his own expense to replace the said work or material to the satisfaction of the Engineer Commissioner. In case the contractor shall neglect or refuse, after written notice, to remove or replace said rejected work or material, it shall be removed and replaced, by order of the Engineer Commissioner, at the contractor's expense.

The work is to be commenced and carried on at such times and places and in such manner as the Engineer Commissioner shall direct.

The contractor will not be allowed to obstruct private driveways or approaches or to dig up or occupy the street by material more than is absolutely necessary for the prosecution of the work, special care being taken to inconvenience the public as little as possible.

When the construction of any piece of work is begun it shall be fully completed before the force is removed. In case this is not done, the Engineer Commissioner shall have the work done, and the expense thereof shall be charged to the contractor and deducted from his estimates.

If any overseer or workman employed by the contractor shall be declared by the Engineer Commissioner to be unfaithful or incompetent, or shall refuse to obey the instructions of the inspector, the contractor shall forthwith dismiss such person and not again employ him on any part of the work. The contractor will be held responsible for all injury done to the work in any way until it is accepted and measured by the engineer.

Measurement of Work.—All artificial stone-block walks, including stone and mortar foundation, will be paid for by the square yard of finished surface, in accordance with the schedule in printed form of bid, except when it is fitted around poles, lamp-posts, or scuttle-holes, in which case these spaces will not be deducted. Tree-spaces will not be deducted.

Curb.—Whenever ordered the curb will be reset. Curb will be redressed by the contractor whenever ordered, for which actual cost plus 15 per cent will be paid.

Tree-spaces.—Tree-spaces shall be left wherever necessary. These spaces shall be outlined by boards of sound Georgia pine, 2 inches thick and 9 inches wide, set on edge, with their top edge even with the pavement when completed. The plank forming the rear of this framework and which is parallel with the curb shall be firmly nailed to the other two pieces, and shall be cut in such manner that it will bind underneath the pavement when completed. The blocks shall be laid as closely to the boards as possible, and all corners and vacant spaces shall be filled with mortar similar in composition to that of which the blocks are made.

797. Tar Concrete for Footway Pavements is made in many and various ways. Pavements made according to the following specifications have proved satisfactory:

Proportions of materials:

Steam ashes	3 parts
Portland cement	1 part
Sharp sand	1 "
Gas-tar	9 parts
Water	70 to 80 "

Method of Mixing.—The ashes, sand, and cement are thoroughly mixed dry, then the water and tar added and mixed in the same manner as mortar. The plastic mass thus produced is passed several times through a pug mill: if this is not done, the concrete will be a failure. As the mass emerges from the mill a large proportion of the water will run from it, and means must be provided to allow it to escape freely.

The foundation is prepared in the usual manner and the concrete laid 3 to 4 inches in thickness, well rammed with hand rammers, then rolled with an iron roller weighing not less than 600 pounds—the amount of rolling to be not less than two hours for each 100 square feet. Hollows that appear during the rolling to be trimmed and filled up. After the concrete is set sprinkle a small quantity of clean, sharp sand over the surface and allow it to remain for three or four days after the path has been in use, then remove it.

The concrete should not be laid in wet or freezing weather.

798. Another method of forming tar-concrete pavements is as follows: On a dry foundation is placed a coat of rough clinkers from anthracite coal, or iron clinkers from a foundry, mixed with sand and tar in the proportions of 15 cubic feet of fine sifted ashes, 14½ cubic feet of pit sand, and 1½ cubic feet or 9 gallons of tar. This is laid about 3 or 4 inches thick and well rolled. Over this is placed a coating from 1 inch to 1½ inches thick, composed of 15 cubic feet of coarse sifted ashes, 15 cubic feet of clinkers, and 1¼ cubic feet or 8 gallons of tar. It must then be well rolled and sanded, care having been taken that the materials are thoroughly mixed.

799. Footway pavements of which the binding material is coal-tar must only be reckoned as temporary. They have been extensively used in several cities, but as a rule they soon wear out and become very disagreeable. Under a hot summer sun the pavement becomes soft and sticky, the volatile oils are evaporated, and the surface becomes covered with ridges; they are difficult to repair and are never satisfactory.

800. Gravel.—For suburban streets, country roads, parks, and pleasure-grounds, gravel makes an excellent footway pavement.

The same rules that apply to the construction of gravel roadways apply to gravel footways. They must be well drained and well rolled.

Limestone chippings may with advantage be used with pit gravel. For paths formed of gravel a crowning surface looks better and is more enduring than a sloping one. (See Fig. 149.)

801. As examples of excellent rural-walk construction, the walks of Central Park, N. Y., may be cited. These walks embrace, in treatment and materials, the requirements of the generality of rural walks in this country. They are laid on every variety of ground, from level and smooth to rocky and precipitous, sometimes clambering with rustic steps and winding narrowly along rugged hillsides; sometimes gently undulating over meadows and lawns, and sometimes expanding into broad and capacious promenades. They are carried over and under roads, and over brooks, by archways and bridges of various kinds, ornamental and rustic; through gorges and ravines, and along the water edge of lakes and ponds. They are made of various widths, from 3½ to 35 feet, and adapted to nearly every circumstance of position, locality, use, and convenience that ordinarily occurs in walks for rural or park purposes.

802. The general method of constructing the walks was as follows: In the more formal walks—those having the greatest breadth and occupying ground that was originally so irregular and uneven as to require a considerable amount of excavating and filling—the preparation of the bed of the walk was the same as for the roads. Care was taken to compact the earth in the embankments, excluding all perishable and improper materials.

The bed of the walk was raised in the centre, with a moderate inclination toward the sides, and where not sufficiently firm was rolled with a hand- or horse-roller. The sub-drainage was secured by drains formed sometimes of tiles and sometimes of rubble-stone, so placed as to intercept and carry off the water from rain and springs. "Mitre drains" formed of small stones were employed where necessary.

803. One of the principal causes of the deterioration of walks, and a prolific source of trouble and expense in repairs, is the wash from water brought from the adjoining slopes. If the expense of

making good the damage done in this way—sometimes by a single shower—is considered, it will be seen that a liberal and ample provision to guard against it is warranted by sound economy. No cheaper or more effective and practical method can be adopted for this object than the catch-water drains, or, as they have been termed in the Park, "sod gutters."

These are made along the uphill side of the walk, in the form of a broad grave, parallel for the most part with the walk and a few feet from it, and joined by an easy graduation of surface to the ground on each side, so as to give them as little of an artificial appearance as practicable. The bottom is made even and regular, with no depressions to lodge silt or mud, or form pools of water. When properly shaped the surface is sodded and rammed.

After the grass has taken root, the gutter will bear the passage of a considerable volume of water for as long a time as is ordinarily required, without receiving injury. This form of gutter admits of the mowing of the grass that grows in it without difficulty, which is a great convenience. If the walk passes through a hollow, with descending ground from each way, these gutters are made on each side of the walk. When it occupies ground that is level transversely, it is raised slightly above the surface, to give an outward inclination to the turf borders and turn the water away from it.

The gutters are conducted along the walk, parallel with it, or deviating occasionally to take advantage of convenient natural depressions, until a favorable point is reached for turning off the water altogether, and disposing of it in a secure manner. Where it is practicable, the water is allowed to spread out from the termination of a gutter upon a broad surface of descending ground, and seek the general drainage courses of the district in which it is situated, that lead to a sewer inlet, a brook, or a pond. Sometimes the gutter is conducted to a sewer or road drain in the vicinity; but when facilities of this kind are not available, and it is objectionable or unsafe to discharge an accumulation of water upon a lawn or through shrubbery, special under-drains have had to be constructed. Such under-drains have been necessary, to a considerable extent, in connection with most of the main walks of the Park. They receive through grated inlets, inserted in the gutters (with accompanying silt-basins), the immediate drainage of the walks, and, through similar inlets placed in the adjoining sod gutters, the exterior

drainage. Fig. 161 shows the arrangement of these drains, inlets, and silt-basins. The depression on the right of the figure shows in section a sod gutter (or a natural surface channel), having an inlet to the main and under drain through a silt-basin, which is represented under the right walk gutter. The inlets and silt-basins occur in this manner at intervals of one hundred to three hundred feet, according to circumstances, the amount of drainage, the declivity of the walks, etc. The under-drain is carried various distances along the walk, until it becomes convenient to turn it into a larger road-drain or a sewer.

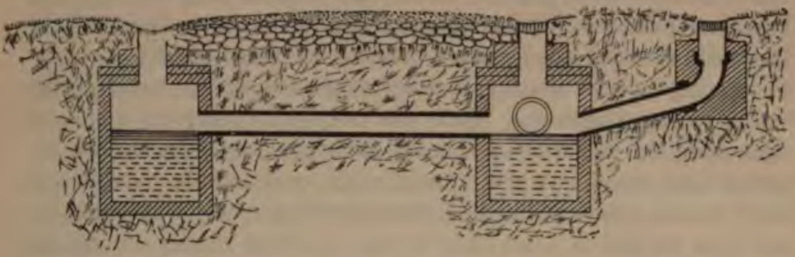


FIG. 161. SECTION OF PARK WALK, SHOWING THE MANNER OF REMOVING THE SURFACE WATER.

Where the under-drains and silt-basins are omitted, which is the case with the narrower and more irregular walks, the drainage of the surface of the walk is conducted off to the ground beyond, or to a sod gutter, through openings in the border of the walk that are made at suitable points.

804. The footway is formed of rubble and small or roughly broken stones, deposited generally eight inches deep for a foundation, with about two inches of gravel spread over the top to receive the wear. The stones are such as are obtained from the earth excavations in grading the walk and adjoining grounds, or from blasted rock and bowlders, or field stones picked off the surface of the ground, or cobble-stones thrown out from gravel excavations, etc., as may be found convenient in any case. Blasted or quarry stones are preferable when they can be had in sufficiently small sizes, and without incurring the expense of quarrying them specially for the purpose. The sizes should be such as to admit of making up the layer of eight or ten inches deep, in two courses, or so that

no single stones shall reach through the whole layer, and prevent the effectual closing of interstices. Quarry stones are better than field stones, for the reason that they are more angular and irregular in shape, and make a more open or cellular foundation to facilitate the drainage and prevent the action of frost.

805. A bed of stones laid in such a way as to permit the surrounding spaces to be filled up, either by the wash of mud along the bottom, or by the sinking of the stones in the bottom (in consequence, frequently, of defective drainage), or by the gravel or surface material working down from above, is but little better than a bed of natural stony ground, for it absorbs and retains all the water that reaches it, until it fills up and overflows at the surface, making the walk wet and spongy, and inviting all the difficulties and deteriorating results that it is a principal object in constructing walks to guard against. Walks are frequently observed that have been made in this way—a mass of stones having been thrown together in a trench on wet ground, with considerable trouble and expense, and the unprotected interstices filled solidly with mud that has been washed in from time to time (perhaps mostly during the process of construction), until no room is left for the percolation of water from the surface, and the saturated bed is in a condition to be operated upon to the fullest extent by frost. It ought not to be a matter of surprise, although it sometimes is, with those who make such walks, that they do not give satisfaction at all commensurate with the expense and labor bestowed upon them.

806. When the layer of stones is formed of requisite depth, and some pains taken to regulate and adjust the surface by settling, breaking, or replacing stones that are too large or that project too high, and filling with smaller stones or covering the larger apertures, a coating is then spread over of quarry chips or such finer rubble or coarse gravel as may be available. In case such materials cannot be had, soft, shelly, or partially decomposed stones are selected and broken up on top of the layer, until the interstices are sufficiently closed to admit of following the process with a light film of gravelly loam or other coarse earth, which latter material, after being evenly distributed and moistened is well rolled by hand-rollers. This prepares the surface of the bed—when the work is carefully and thoroughly performed—for the reception of the final covering of gravel.

807. The perfection of the work consists, up to this point, in forming a stable and unyielding foundation, with the interstices of the main body of stones kept free and unobstructed, and a covering, to support and retain the superincumbent gravel, of the least thickness and density that will enable it to serve its purpose. A fair test is afforded of the sufficiency of the surfacing material by letting the work stand, after the rolling is done, until it has been exposed a few days to the weather: if it sinks away into the stones below, forming holes and leaving the stones naked and roughly projecting, it shows that enough material has not been added, and such spots should be well repaired; if it retains water (from rain), forming a muddy surface that does not filter away and dry out readily, it shows that more earthy material has been used than is beneficial. The proper surfacing of the bed of stones will not ordinarily add much to the average depth of the layer, just covering the highest points of the stones, and filling over smoothly the intervening inequalities, so that the gravel, when it is applied above, will have a uniform depth and conform to the desired crowning shape of the walk.

808. If gutters are required for the walk, the foundations for them are prepared by using, in the outer edges of the stone filling, smaller stones and gravel for the better support, and to facilitate the setting of the gutter stones.

809. The gravel is deposited on the walk two or three inches deep, the coarser part being raked forward into the bottom of the layer, and such pebbles as are too large picked off. When evenly adjusted, a film of sandy or clayey loam is spread over the surface and lightly raked in to aid the binding effect, and after the whole is moderately watered or moistened, the completing process of rolling and compacting is commenced. This is done, on the principal walks, by a roller drawn by a horse; on narrow walks and those having greater acclivities, regularities, rustic steps, etc., it is done by a roller of less weight, drawn by hand, by two, three, or four men, as the case may be. As the rolling proceeds, a man follows with a rake, to correct inequalities and keep the binding material equally diffused through the gravel, and to add more of such material, from time to time, as may prove to be necessary. Judgment and expertness are required to manage this business well. Dull or unpracticed men will waste their time at it. The quantity of

binding material that is judicious to use will vary sometimes with each load of gravel: if too much is used, or if it is unevenly and carelessly spread, it will produce an imperfect surface, and it will take considerable time and labor to correct after the walk is brought into use. If the gravel is fine and filled with dirt, or if the grains are of a soft, friable quality, it will not need as much foreign material added to make it bind as when it is clean and hard: it may contain such a quantity of earthy matter, however (as is frequently the case), as to make it necessary to free it from a portion of the binding substance by screening, rather than to add to it: such gravel should not be used if better can be had. All muck, top-soil, and vegetable or fertilizing matter should be carefully excluded from both the gravel and the binding material, to prevent the growth of grass in the walk. The gravel that has been used in the Central Park walks has generally been of a sharp, hard quality, and more than usually free from dirt, and it has been found that it would bear an average intermixture of about one fifth its bulk of loamy or sandy earth to give it the requisite binding property. If more than this was added, the work of rolling and packing would be facilitated, but the surface of the walk would absorb and retain water, and become muddy after a rain; if less was added, the rolling, although it might be thoroughly done, would not suffice to make a surface that would remain firm in dry weather.

810. The effect of the proper adjustment of these points, the selection of a good quality of gravel, the judicious use of the binding material, and the raking, shaping, and rolling, is to produce a walk that is agreeable at all times: not muddy or slimy after a rain, or loosened so that the foot sinks into it when it becomes very dry, or much subject to dust.

With care and some sleight in the raking, before and after the rolling is commenced, the finer gravel and sand will be worked to the top and the coarser pebbles buried in the bottom of the layer, preventing the disagreeable feeling that is caused by walking over a coarse or unequal surface.

811. In investigating the subject of walk drainage and gutters, in the early stage of the Park work, experiments were tried in order to ascertain if some better or cheaper or less objectionable description of gutter could be devised than those in common use. Although the results attained were not such as to warrant the adop-

tion upon the very uneven grounds of the Park of any of the kinds of gutter experimented upon, yet they may afford some hints and possess sufficient interest to be worthy of mention.

The principal kinds were as follows:

(1) Cement or concrete gutter.
(2) Composition gutter.
(3) Iron gutter.
(4) Wood gutter.

Nos. 1 and 2 were open gutters. No. 1 was composed of a concrete consisting of two parts of gravel and sand and one part of cement laid on a filling (adjoining a walk east of the Mall), of broken stone and gravel of about 9 inches in depth. The concrete was deposited 2 to 3 inches thick, and moulded by the aid of a wooden implement drawn over it into the desired form. The gravel of the walk and the side border were closed up to it on either side, and completed the process.

This gutter was comparatively cheap and easy of construction, and appeared in all respects, as regards utility, well adapted to the purpose. After exposure to the weather for a time, it became lighter in color than the gravel of the walk, owing to the cement which entered into its composition. The objection to it at the time of trial (1859) was the uncertainty of its durability, together with the general objection to all open or surface gutters—that it gave too marked and formal an outline to the walk. The sample is still in its original position. It has improved in respect to color, and has been but little affected by the changes of weather or frost or by wear.

No. 2, composition gutter, east side of "the Ramble," was made in a similar manner to No. 1 as to form and dimensions, but the materials used and its manipulation were not disclosed by the gentleman who introduced the sample and supervised its construction (Gen. Asboth). The principal defect of this gutter seemed to be the contraction of the materials, which separated on exposure into broken sections—the action of frost and other causes tending to increase it and displace the parts. It was also open to the general objection mentioned to all formal gutters.

No. 3, iron gutter, was made of light sheet-iron, in sections of U-form, with a perforated movable lid or cover. The design was to make it a concealed gutter by sinking it along the edges of the

walk and covering it over with a light layer of gravel—the surface-water to percolate through the gravel and the perforations in the lid into the gutter, and thence pass off as through a pipe. This sample, as far as tried, indicated that it might be made to operate well in ordinary cases of moderate drainage and not too great inclination of the walk, but it was considered to be subject to too many contingencies for general use.

No. 4, wood gutter, was constructed upon the same principle as No. 3, with the substitution of wood for iron. It was a mere wooden trough with a perforated lid, the wood having been subjected to a process to give it greater than ordinary durability. It was apparent that it was inferior to the iron gutter (though much cheaper), and its general want of adaptability was considered as decisive against it.

A method of macadamizing gutters of the common (open) form was tried in order to obtain a gutter that would blend, better than ordinary paved cobble-stone gutters, with the gravel of the walk, and not present the usual contrasts of color and kind of material, but it was found impracticable by ordinary means to give the materials sufficient compactness and cohesion to resist long the action of a current of water. The same process was tried for the surface of a narrow walk, on steep ground, where it was difficult to make the gravel remain during rains, and with the same results.

These experiments (although not wholly failures) serve to show that the safest and probably the most practicable means that can be adopted for the drainage of walks in general are such as have been gradually brought into use in the Park, in the manner that has been previously described.

812. General Directions for the Construction of Gravel Walks.

(1) Excavate a trench the width intended for the walk, ten to twelve inches deep, leaving the bottom even and regular and slightly crowning in the centre, unless the walk is to be quite a narrow one. If the ground is not hard and firm, pass a garden-roller a few times over it. If it is wet and heavy, lay a line of 1½-inch drain-tile (using collars) along the walk as near the centre as practicable, and at a sufficient depth to be below the reach of frost.

(2) Fill the space excavated for the walk six to nine inches deep with field or quarry stones, placing the smallest on top. Select the softest and easiest stones to break, and hammer them up on top of

the stone filling until the interstices are sufficiently filled to exclude the gravel. Rotten or partially decomposed stones will answer well for this purpose, or, if this material is not convenient, use a light layer of gravelly loam or hardpan. The surface will be further improved, previous to putting on the gravel, by sprinkling it and going over it a few times with the roller. The object of the process thus far is to secure a firm, well-drained foundation for the walk, having the surface interstices of the stone filling sufficiently closed to prevent the gravel from running down and filling up the voids below, and yet leaving free vent for surface-water to percolate through.

(3) If the stone filling is well prepared in this way, and the surface made even,—no points of large stones projecting, etc.,—two inches in depth of hard fine gravel will be sufficient to complete the walk. In applying the gravel a light layer should at first be put on and raked over evenly, working the coarser gravel forward into any interstices or inequalities of the stone filling. Moisten this layer and roll it down firmly and evenly. The second and last layer, to make the most complete and agreeable surface, should be passed through a screen the meshes of which are not more than $\frac{1}{16}$ of an inch wide, and care should be taken in applying it not to rake up the first layer, and to spread it evenly—holding the handle of the rake nearly perpendicular. If it is not screened, more pains must be taken (with a fine rake) to exclude from the surface gravel that is too coarse and unequal in size to be agreeable to the foot. Next and lastly, sprinkle and roll the whole thoroughly. The gravel should not be drenched, but only made moist or damp in order to pack well under the roller. Until the walk has had some wear, it will be necessary, after dry weather, to trim the surface anew with the back of the rake, and to repeat the rolling occasionally. Roll after a light rain, but never when the gravel is dry or when too wet.

(4) A slight intermixture of clay or loam with the gravel will serve to make it pack or "bind" more firmly when desirable, and with less use of the roller; but this should be done with moderation, and no vegetable mould should be introduced to encourage the growth of grass or weeds. It is a great advantage to procure pure gravel: its freedom from earthy or vegetable matter prevents not only vegetation from taking root, but the liability to dust in dry weather and a muddy or slippery surface in wet weather. It also

prevents the action of frost. It is better, therefore, to avoid any intermixture of other substances that will defeat these objects.

(5) The surface of a walk should be a little crowned in the centre, and should be provided with outlets through the grass borders, at suitable points, to carry off sudden accumulations of water. Where the walk has much inclination, and also where the outside drainage from adjacent ground is liable to be brought to it, more frequent outlets, cross-drains, etc., must be made.

(6) If, for any considerable distance along the walk, drainage-water from sudden rains cannot be conveyed away from it securely by these means, gutters must be made. These can be made in a variety of ways, but there are no gutters that give more permanent satisfaction, at a moderate cost, than those formed neatly with small cobble-stones. Suitable stones for the purpose can generally be selected from the gravel delivered for the walk, or from the pit from which it is obtained.

(7) A system of walks, extending over a large area of ground that is not naturally adapted to easy surface drainage, must have one or more main under-drains with subordinate or branch drains entering them from various points of the system, and with inlets from the gutters of the walks, silt-basins, etc., all of which must be adapted to the local circumstances in each case by special study or survey, and no general rule can therefore be given for their treatment.

(8) A walk can be cheaply made on light, well-drained soil by simply removing the turf to the depth of three or four inches and filling the space with gravel, raking the coarse forward into the bottom and leaving the fine on top. One half of the gravel, in this case (in the bottom), may be of inferior quality.

813. Curbstones.—Curbstones are employed for the outer side of the footways to sustain the coverings and form the gutter. Their upper edges are set flush with the footwalk pavement, so that the water can flow over them into the gutters.

The materials employed for curbing are the natural stones, as granite, sandstone, etc., artificial stone, fire-clay, and cast-iron.

The dimensions of curbstones vary considerably in different localities, and according to the width of the footpaths the wider the path the wider should be the curb. It should, however, never be less than 8 inches deep, nor narrower than 4 inches. Depth is

necessary to prevent the curb turning over towards the gutter. It should never be in less lengths than 3 feet. The top surface should be bevelled off to conform to the slope of the footpath. The front face should be hammer-dressed for a depth of about 6 inches, in order that there may be a smooth surface visible against the gutter. The back for 3 inches from the top should be also dressed, so that the flagging or other paving may butt fair against it.

814. Setting Curb requires care and an experienced workman, for as it is set dry, great care must be exercised to set it true to level and line. It must be well rammed and bedded or it will sink, turn slightly over or move, even months after it has been set. Curb-stones carelessly set will never present a pleasing appearance.

815. In localities where stone is not obtainable, artificial stone, fire-clay curb, and cast-iron afford excellent substitutes. Artificial stone under the name of Asbestine Building-stone is used in some of the Western cities: it is manufactured from German Portland cement, sand, and broken stone.

Fire-clay curbing is extensively used with brick pavements: some of the usual forms are shown in Figs. 162 to 166.

Cast-iron is employed in some cities in France; it is cast in L-shaped sections, as shown in Fig. 167.

816. Specifications for Standard Granite Curb (Washington, D. C.).—The curbing must be of good and acceptable texture and color, dressed 12 inches on the face, 3 inches on the back, and chiselled 6 inches deep on the joints, with no projections beyond the chiselled portion of the joint; the joint to be at right angles to the face and top surface; the top surface to be bevelled ¼ inch; the face and top to be plane surfaces, without depressions or irregularities. The length must not be less than 6 feet, depth not less than 20 inches nor more than 24 inches in any portion of a piece, and thickness 6 inches. The bed of the curb must average not less than 6 inches in width, and no excessive protuberance will be allowed on the sides.

817. Special 8 by 8 Inches Granite Curb.—The curbing must be of suitable and acceptable color and texture, dressed on top and the full depth on the face, and 3 inches deep on back. The top surface will be bevelled ¼ of an inch. The face and top to be plane surfaces, without bends, twists, depressions, cups, or other irregularities. It will be 8 inches thick, not less than 8 inches nor more

than 12 inches deep, and no piece less than 6 feet long. The joint will be chiselled throughout. The bed will be rough-dressed to give secure bearing.

818. Specifications for Bluestone Curb (Washington, D. C.).— The curbing must be best North River bluestone, dressed 12 inches on the face and 3 inches on back, and chiselled 6 inches deep on

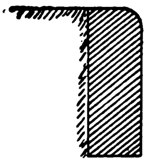


Fig. 162.

FIRE-CLAY. CURB

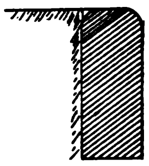


Fig. 163

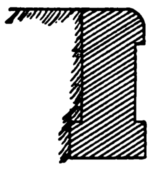


Fig. 164.

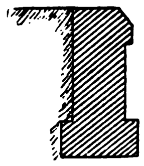


Fig. 165

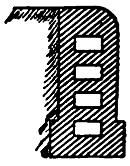


Fig. 166.

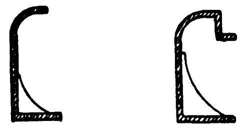


Fig. 167. IRON CURB

the joints, with no projection beyond the chiselled portion of the joint; the joints to be at right angles to the face and top surface. The top surface will be bevelled ¼ of an inch; the face and top to be plane surfaces, without bends, twists, depressions, cups, or other irregularities. The length must not be less than 4 feet, depth not less than 20 inches, and not more than 24 inches in any portion of a piece, and thickness 5 inches. Each piece must have a bed not less in area than the dressed portion of the curb, and no excessive protuberance on the sides.

819. Circular Curb.—Circular curb will conform in all respects to the specifications for straight curb, except that it will be cut to the required radius. It must be cut to such lengths that three pieces will make a 90-degree curve.

820. Specifications for Curbstones (New York).—The curbstones shall be of the best quality of North River bluestone, 5 inches thick, and not less than 4 nor more than 8 feet long, and 20 inches deep, cut and smooth dressed on the front to a depth of 14 inches, bevelled on top to the slope of the sidewalk. Ends shall be accurately squared, so as to make close joints the whole depth.

821. Specifications for Setting Curb (Washington, D. C.).—The trench will be dug 24 inches deep and 18 inches wide, to permit a thorough ramming. A bed of gravel 4 inches deep will be laid in the bottom of the trench and thoroughly consolidated. On this bed the curb will be laid to level and grade with close joints and even and continuous surfaces. The ditch will then be filled with gravel, the first filling to be not more than 3 inches deep, be well rammed by rammers or bars so as to give the curb a solid bearing under its entire length. Other layers will then be rammed in the ditch to within 10 inches of the top of the curb; the layer for each ramming to be not more than 4 inches deep.

The special granite curb will be laid on a foundation of hydraulic concrete, as shown in Fig. 168.

On the gravel-bed the concrete foundation made as prescribed for the concrete base for standard asphalt-pavements will be laid. This concrete base will be laid of such depth as to permit the granite curb (of which the depth will vary generally from 3 to 12 inches) to be placed upon it and remain at the proper grade. All spaces remaining between the curb and the concrete foundation will then be carefully rammed completely full with cement mortar or fine concrete suitable for the purpose. The necessary concrete will then be added to bring the foundation to the dimensions shown in the cut. The work of setting this curb will be done by competent stone-masons. If so desired, the contractor will be authorized to finish the foundation in front of the curb with a layer of binder, as prescribed for the intermediate course in coal-tar distillate pavements, but no extra allowance will be made for such work.

822. Specifications for Artificial Stone Curb and Gutter (Washington, D. C.).—A combination curb and gutter of artificial stone

on concrete foundation will be laid on streets, as may be ordered by the Engineer Commissioner. The curb, gutter, and foundation will conform with the dimensions given on drawings on file in

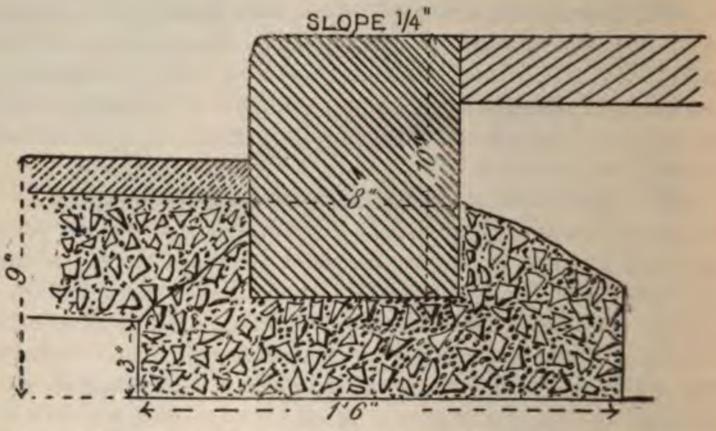


Fig. 168 GRANITE CURB (WASHINGTON, D.C.)

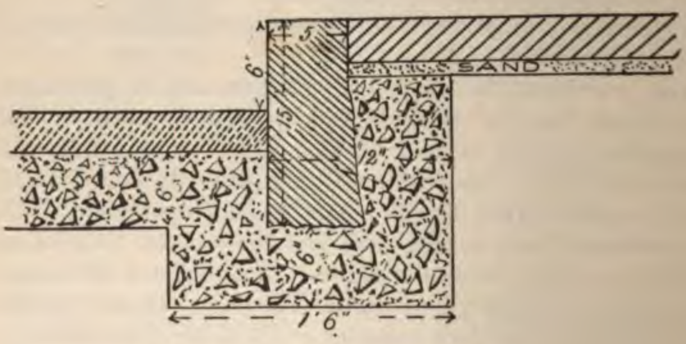


Fig. 169 BLUESTONE CURB.

Engineer Department. The concrete foundation will be composed of the same materials and will be laid in the same manner as prescribed for concrete foundations of asphalt pavements. The curb and gutter will consist of fine concrete composed of one part Port-

land cement, two parts clean sharp sand, and three parts clean broken stone not more than 1 inch in their largest dimensions. The exposed surfaces of both gutter and curb will be coated 1½ inch thick with a cement composed of three parts granulated granite (the fragments being of such size as to pass through a quarter-inch screen and free from all dust), and two parts of cement.

The cement used in the manufacture of the curb and gutter must conform to the current District of Columbia specifications for slow-setting Portland cement. The work will be carried on uniformly, and the whole curb completed while in a soft and plastic state, so that it will become a homogeneous solid when set. While still plastic the curb and gutter will be saw-cut at intervals of 8 to 10 feet, as may be ordered, to allow for expansion and contraction, and to give the appearance of cut stone.

Contractors may use such methods of moulding the curb into shape as they may deem best fitted to the work. The curb and gutter when set must conform with the cross-section shown in drawing.

A conduit for electrical conductors, 4 inches wide and 4 inches high, will be left at the base of the curb if so ordered by the Engineer Commissioner. Hand-holes, to give access to this conduit, will be left at intervals of 50 feet, more or less, as may be ordered, all to be as shown on the drawings. Man-holes will be constructed near each cross-street in accordance with plans and specifications on file in Engineer Department. The exact location of each man-hole will be fixed by the Engineer Commissioner. The cost of these man- and hand-holes, and their frames and covers, must be included in the price per linear foot of the "combination curb and gutter" with electrical conduit.

The curb and gutter must be properly protected from injury while setting, and the material used for such protection must be removed within twenty-one days from the completion of work, if so ordered.

The contractor is required by law to guarantee all work for the period of five years from the date of the completion of the contract.

823. Specifications for Dressing Old Curb.—Old curb will be dressed by the contractors for street improvements whenever ordered by the engineer.

Contractors will employ competent stone-cutters to do the work,

and will be allowed the actual cost of the labor employed plus 15 per cent, for tools, sharpening same, and supervision. Certified pay-rolls of men employed and amount paid will be required for each street.

824. Re-setting Curbstones.—The curbstones along the line of the work shall be readjusted and brought to the grade, and lines given by the engineer, without extra charge therefor. All curbstones on the line of the work that are cracked or broken, or otherwise damaged, shall be re-dressed so as to conform practically in form, size, and quality to the requirements of the specifications for new curbstones. New stones shall be furnished when necessary, without extra charge therefor.

825. Hollow sidewalk curbs are shown in Figs. 170, 171; they are especially designed as a conduit for electric wires or cables or for pipes. They are the invention of Mr. E. Greyson Banner, of London, England.

The principle is shown in Fig. 170 in its simplest form. The block, *a*, may be of concrete, through which the channels *cc* are

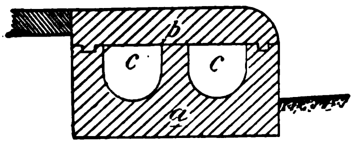


Fig. 170.

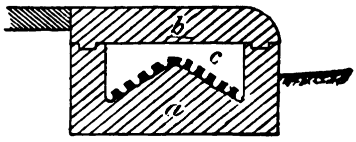


Fig. 171.

HOLLOW CURB.

moulded, and which are accessible upon the removal of the flag *b*. This flag may be continuous in the case of pipes, but for wires, etc., it may be so arranged with hand-holes at short intervals.

Fig. 171 is a modified section for use where the wires are to be kept at a distance apart, for the sake of greater insulation, each wire having a separate channel.

The curb may be formed in place or manufactured at a factory, in which case the blocks, to secure alignment, are made with projections on one end which fit into corresponding recesses on the other.

826. Gutters.—In streets covered with broken stone a stone gutter is necessary. It may be formed of either stone slabs or pav-

ing-blocks, the latter being the better. It should be not less than 18 inches wide. If formed of paving-blocks, the blocks should be laid with their length parallel to the curb, bedded on gravel, and well grouted in with bituminous cement.

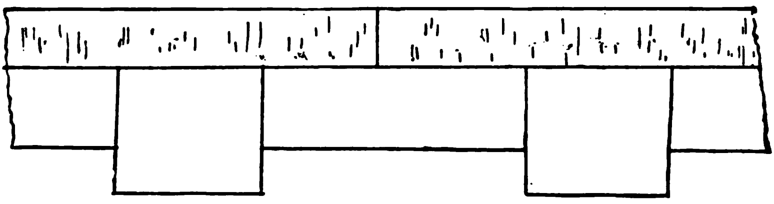


FIG. 172. PLAN SHOWING MANNER OF LAYING GUTTER-STONES.

When stone slabs are used, they should be not less than 3 feet long, 6 inches thick, and from 10 to 15 inches in width. They should be laid alternately (see Fig. 172); for if of uniform width, the continuous longitudinal joint between the gutter and the rest of the pavement will quickly wear into long deep ruts or grooves, which causes severe strains upon the running-gear of vehicles when the wheels, having once entered the rut, attempt to leave it.

The gutter should have the same slope as the roadway, and the curb should show seven inches or more above it.

In streets paved with asphalt granite blocks or bricks the same material is used for the gutters; the blocks being laid with their length parallel to the curb, instead of transversely as in the street itself.

827. Specifications for Laying Cobble Gutters and Crossings.— The cobblestone and flagging will be furnished by the along the line of the work.

The materials necessary to be removed shall be excavated to a depth of 12 inches below the top line of the proposed gutter or crossing when fully packed. Any objectionable or unsuitable material found below that depth must be removed, and the space filled with clean sand or gravel.

All holes or inequalities shall be filled to a proper level with sand or gravel well compacted by ramming or rolling. Upon the foundation thus prepared shall be laid a bed of good bank gravel, 5 inches in thickness, thoroughly compacted by rolling or ramming.

Upon this shall be spread a layer of clean, sharp sand, to serve as a bed for the paving-stones, of such depth as may be required to bring the work to grade.

The cobblestones shall be assorted as they are brought upon the ground, and no stones that are less than 4 or more than 6 inches long, or less than 2 or more than 4 inches wide, shall be used, and the several sizes must be laid so as to make an even surface when rammed. When thus laid the stone shall be immediately covered with clean, fine sand, in proper quantities, and raked until the joints become filled therewith; the stones shall then be thoroughly rammed to a firm, unyielding bed with a uniform surface and proper grade.

The foundation for the gutter and crossing-flag shall be prepared in the same manner as described for cobble, upon which the flag shall be laid with close joints and settled into place solidity in such a manner as not to fracture the flag. When gutters are laid without curb, selected stones of large size shall be laid to line in the position and at the height that the curb would be if laid. This course must be laid true to line and grade and with especial care. Gutters will generally be 4 feet wide, with 12-inch flagging in the centre.

828. Specifications for Brick Gutters.—Whenever ordered on streets to be paved with asphalt, brick gutters will be laid. The materials necessary to be removed shall be excavated to a depth of $8\frac{1}{2}$ inches below the top line of the proposed gutter. Any objectionable or unsuitable material found below that depth must be removed and the space filled with clean sand or gravel. All holes or inequalities shall be filled to a proper level with sand or gravel well compacted by rolling or ramming. Upon the foundation thus prepared there will be placed a layer of hydraulic-cement concrete 4 inches in thickness. This concrete layer shall conform, in all respects except depth, with the concrete base as specified herein for standard asphalt pavements. Upon the concrete base so prepared paving-bricks shall be placed on edge with their lengths at right angles to the curb and breaking joints in the direction of the curb. The outer edge of the gutter shall be left with alternately projecting bricks to tooth into the asphalt pavement.

The bricks must be so laid that the upper surface will be smooth and at the proper grade.

Immediately after the completion of the asphalt pavement adjacent to the gutter, hot paving-tar shall be poured into the joints of the bricks until it rises to the surface. The gutter shall then be covered with a sprinkling of sharp dry sand. If so ordered, instead of the hot paving-tar a grouting of Portland cement and sharp sand in equal proportions, mixed with a sufficiency of water to make a thin grouting, will be used. The bricks for this gutter-paving will be furnished by   at its property yards, and hauled thence to the site of the work by the contractor for laying them.

Bricks for gutters may be furnished by the   at the site of the work. A separate bid is requested for the work if bricks be so furnished.

829. Specifications for Gutter-stones.—The gutter-stones to be of   stone, not less than 4 feet long and 10 to 16 inches wide, and 4 inches thick throughout; to have a smooth surface free from winds, seams, or other imperfections; to be cut and squared so as to form close joints with each other and with the curb.

The stones shall be laid, at the grade furnished, on a bed of sand 2 inches thick. The joints of the stones shall break joint with the joints of the curb. The stones shall be laid narrow and wide alternately. The joints shall be filled with a bituminous-cement or Portland-cement mortar.

830. Crossing or Bridge-stones.—Street-crossings are footways provided for pedestrians; they are formed of two or more rows of stone slabs, usually with one or more rows of paving-blocks between them.

The stone used for crossings should not be less than 3 feet long, 10 inches wide, and 6 inches thick, with the top surface hammer-dressed, the ends squared and dressed so as to form a close joint for the full depth of the stone. Without close joints it is impossible to maintain a good crossing. With defective joints gaps are quickly formed and each successive vehicle falls into the hollow so formed with increasing force until the stone is destroyed. Crossing-stones should not be of too great width or of a stone that wears smooth; if so, they will afford little foothold for horses and will otherwise be very objectionable.

Sandstone is superior to granite for this purpose.

At street-crossings the bridge-stones should be kept level with

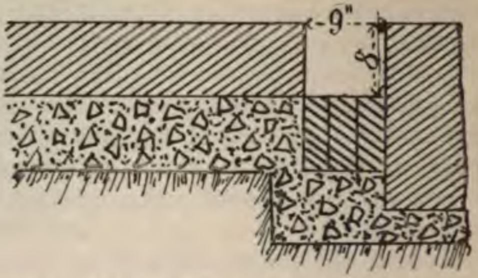


FIG. 173. SECTION AT CROSSING SHOWING GUTTER PAVED WITH STONE BLOCKS.

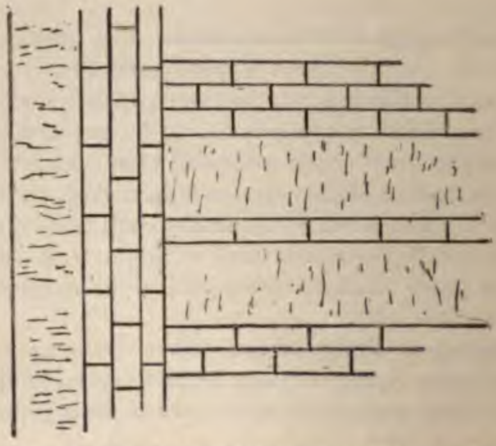


FIG. 174. PLAN OF CROSSING-STONES AND GUTTER-PAVING.

FIG. 175. SECTION OF CROSSING SHOWING GUTTER PAVED WITH A SINGLE STONE.

the curb so that pedestrians may step off the path onto the crossing without any drop (see Figs. 173 to 176).

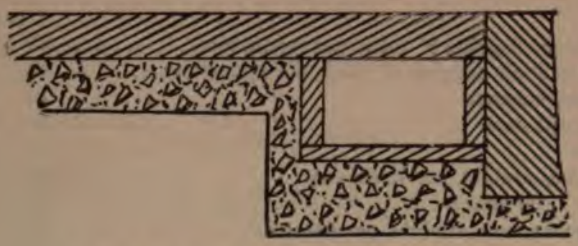


FIG. 176. COVERED GUTTER.

831. Specifications for Bridge-stones (New York).—Bridge, stones to be of bluestone, equal to the best quality of North River bluestone, free from seams and imperfections. Each stone to be not less than 4 nor more than 8 feet long, except in cases where specially permitted, and 2 feet wide, and of a uniform thickness, which may vary from 6 to 8 inches, and dressed to a fall on top not varying in evenness by more than a quarter of an inch, and on the bottom bedded, with sides square and full, and ends cut to a bevel of 6 inches in 2 feet, and in special cases to such other bevel as shall be directed by the Commissioner of Public Works. The stones to be in quality and workmanship equal to the pattern at the office of the Department of Public Works, and to be cut so as to lay a joint not exceeding one fourth of one inch from top to bottom on the ends and one half inch on the sides.

The bridge-stones will be carefully inspected after they are brought on the line of the work, and all those which, in quality and dimensions; do not conform strictly to these specifications shall be rejected and must be immediately removed from the line of the work.

832. Relaying Bridge-stones.—The bridge-stones now on the street shall be relaid without extra charge therefor. If any are found defective, new stone shall be furnished therefor at the expense of the contractor. The stones so furnished must correspond in quality, dimensions, and workmanship to the pattern at the office of the Department of Public Works.

833. Prices.—The prices of the materials employed for footway

pavements fluctuate widely, not only in different but in the same localities; therefore the following prices simply exhibit the extreme range:

	Cents.		
Bluestone flagging 3" thick, per square foot	35	to	95
Granite stone flagging 6" thick, per square foot	40	"	110
Cement concrete " "	13	"	20
Artificial stone " "	18½	"	30
Brick " "	9	"	22½
Granite, straight, per linear foot	85	"	125
" circular, " "	100	"	137
Bluestone curb, straight, per linear foot	35	"	91
" " circular " "	45	"	110
Sandstone curb, straight, " "	35	"	75
" " circular, " "	60	"	100
Brick gutters, per square foot	20	"	38
Granite " " "	40	"	50
Granite bridge-stone per linear foot	70	"	234
Bluestone " " "	60	"	115

CHAPTER XVIII.

RECONSTRUCTION AND IMPROVEMENT OF COUNTRY ROADS.

834. THE improvement of existing roads may be divided into three branches:

(1) Rectification of alignment and grades.
(2) Drainage.
(3) Improvement of the surface.

The first of these consists in the application of the principles which have been laid down for the location, etc., of new roads, and will include straightening the course by extinguishing unnecessary curves and bends; improving the grade by either avoiding or cutting down hills and embanking valleys; increasing the width where requisite, and rendering it uniform throughout.

The second consists in applying the principles laid down for the drainage of new roads, and in constructing the works necessary to give them effect.

The third consists in improving the surface in the best possible manner, either by the forming of an artificial pavement or, if sufficient funds for this purpose are not available, by adopting such local materials as will make a comparatively fair surface.

835. Improving Clay Roads.—Clay soils can only be made into fair wheelways by means of thorough drainage effected by any of the methods described in Chapter XIV.

The narrower the roadway the more effective will be the drainage.

If sand, gravel, ashes, coal-dust, furnace-slag, or shells can be obtained, a coating of any one of them, 4 inches thick, well compacted by rolling, will form an improvement; if none of these materials can be obtained, the clay itself may be utilized by being first burned, then spread and rolled.

The manner of preparing and using the clay is as follows: In summer weather, or during the hot season, the soil in the proposed road should be cut out to a depth of two feet into large spits and laid roughly one upon the other, and left in that condition for about ten days. By this time the sun's rays will have evaporated the moisture held by soils of this nature. So soon as the spits are dry they are submitted to the action of fire in the following manner: A circle is formed fifteen feet in diameter, surrounded by a wall made of the roughest and largest spits, two feet high. In the inclosure thus formed straw or other light combustible material is laid; fagots or small pieces of wood are placed on these, and over them are placed other spits, so as to form a cone or pyramid, the whole structure to be about 8 feet high. Fire is then applied to several parts at once, due care being taken to see that the spits sink evenly until the whole mass is well alight. After being well banked the mass is left for a day or two, and as soon as it attains a good red appearance is drawn down, the wall broken, the spits are thrown on top, and others added as required from day to day, until all the earth dug has been submitted to the same process. In a length of 100 yards of road 20 feet wide thus served, it would take about six fires to burn the 12,000 cubic feet contained therein. The cost of labor would probably be twenty or twenty-five cents per cubic yard. The burnt earth is then, after cooling, relaid upon the road, and now, being of a thoroughly porous nature, settles into a good, dry, solid layer.

Before applying any of the above-mentioned materials to a clay surface all mud and perishable material must be removed. In fact, all the weather-worn clay should be removed to a depth of 18 inches or more, and the surface thus exposed thoroughly consolidated by rolling.

836. In the maintenance of clay roads neither sods nor turf should be used to fill holes or ruts; for, though at first deceptively tough, they soon decay and form the softest mud. Neither should the ruts be filled with field-stones: they will not wear uniformly with the rest of the road, but will produce hard ridges.

Trees and close hedges should not be allowed within 200 feet of a clay road. It requires all the sun and wind possible to keep its surface in a dry and hard condition.

837. Sand Roads.—The aim in the improvement of sand roads is to have the wheelway as narrow and well-defined as possible, so as to have all the vehicles run in the same track. An abundant growth of vegetation should be encouraged on each side of the wheelway, for by this means the shearing of the sand is in a great measure avoided. Ditching beyond a slight depth to carry away the rain-water is not desirable, for it tends to hasten the drying of the sands, which is to be avoided. Where possible the roads should be overhung with trees, the leaves and twigs of which catching on the wheelway will serve still further to diminish the effect of the wheels in moving the sands about. If clay can be obtained, a coating 6 inches thick will be found a most effective and economical improvement. A coating of 4 inches of loose straw will in a few days' travel grind into the sand and become as hard and firm as a dry clay road.

838. The maintaining of smooth surfaces on all classes of earth roads will be greatly assisted and cheapened by the frequent use of a roller (either steam or horse) and any one of the various forms of road grading and scraping machines. In repairing an earth road the plough should not be used. It breaks up the surface which has been compacted by time and travel.

839. Improper Use of Scraping-machines.—The scraping-machine should not be employed to drag the soft mud out of the ditches and place it in the centre of the road. The use of the scraper is to remove from the road-surface the weather and traffic-worn material which no longer possesses coherence, and which, no matter how well rounded up and rolled, will be converted into mud after the first shower of rain. This material, along with that removed from the side ditches, must be deposited in such places where it cannot be washed back on the road-surface. As it consists chiefly of alluvial and vegetable matter mixed with animal excreta, it is useful for fertilizing purposes and may be disposed of to the neighboring farmers; but it must not be left in heaps on the roadside, to be removed by them at their leisure.

840. Cost of Constructing Earth Roads.—The following prices are taken from the bids received for the construction of wagon-roads through the Yellowstone National Park. The specifications were: clearing, 30 feet wide; roadway, 18 feet wide and 6 inches higher at the middle than the edges; on each side a berme of 1

foot, with a ditch on the outer side 5 feet wide at top, 2 feet at bottom, and 18 inches deep. The roadway to be covered with 9 inches of clay or earth.

PRICE PER MILE.

Highest, $4382. Lowest, $2529.

841. Cost of maintaining earth roads ranges from $50 to $80 per annum per mile.

842. Value of Improvements.—The improvement of roads is chiefly an economical question relating to the waste of effort and the saving of expenditure. Good roads reduce the resistance to locomotion, and this means reduction of the effort required to move a given load. Any effort costs something, and so the smallest effort costs the least, and therefore the smoothest road saves the most money to every man who traverses it with a vehicle.

843. Before undertaking any improvement it is generally required to know the cost of the proposed improvement and the benefits it will produce. In the improvement of roads the amount of money that may be profitably expended for any proposed improvement may be calculated with sufficient accuracy as follows. First obtain the following data:

(1) The quantity and quality of the traffic using the road.
(2) The cost of haulage.
(3) Plan and profile of the road.
(4) Character and cost of the proposed improvement.

844. From the data so obtained ascertain the total annual traffic and the total annual cost of hauling it. Next, calculate the annual cost of hauling the given tonnage over the improved road, which may be obtained from the data given in Chapter X. Then the difference between the two costs will represent the annual interest on the sum that may be expended in making the improvement. For example, if the annual cost of haulage over the given road is $10,000 and the cost for hauling the same over the improved road will be $7000, the difference, $3000, with money at 6% per annum, represents the sum of $50,000 that may be expended in carrying out the improvement.

845. For the purpose of ascertaining the amount of money that may be profitably expended in improvements, each part of a given road must be separately investigated as above directed,

because the amount that may be expended varies with the amount of traffic; and as the quantity of traffic using different portions of a road varies, the data obtained close to a town cannot be taken as correct for distant portions, nor the data obtained for distant portions as correct for portions close to towns.

846. The defects of existing roads may be stated as follows:

(1) Unnecessary ascents and descents.

(2) Unnecessary length.

(3) Imperfect surface.

The money benefit accruing from the elimination of any one or all of these defects may be approximately calculated as follows:

847. Profit of Eliminating Grades.—Take for example the elimination of a 5% grade 1 mile long from an earth-road. The observations on this grade show that the daily traffic over it is 224 teams, each dragging an average load of 800 pounds, equivalent to 24,000 tons per annum; that the time occupied in traversing it is half an hour; that the value of a team's labor is 30 cents per hour. Therefore the cost of haulage on this grade is $33\frac{6}{10}$ cents per ton-mile, or $8064 per annum for the total tonnage using it.

From an examination of the ground we find that the grade can be reduced to 2% by constructing a new piece of road 2 miles long, and that the cost of the change will be $18,000.

From the resistance to traction opposed by the new road-surface plus the effect of gravity we find that a team will haul a load, on the reduced grade, of 1200 pounds, and that the time occupied in travelling the two miles will be one hour. Therefore the cost per ton-mile will be 28 cents, or $6720 per annum for the total tonnage. To this add the annual cost of maintaining the extra mile of new road, say $200; this gives $6920 as the cost per annum, which subtracted from the original cost of $8064 leaves $1144; which sum, with money at 6%, represents a capital of $19,066, a sum sufficient to make the proposed change.

848. The money loss caused by grades may be approximately ascertained as follows: Ascertain the cost of hauling a ton on level portions of the same road and on the grade; take the difference and multiply it by the annual tonnage: the product represents the annual loss. For example, the cost per ton-mile on a level is 22.50 cents, on a 5% grade 33.60 cents; difference 11.10 cents = loss per ton, or an annual loss on a traffic of 30,000 tons of $3330, which is

the interest at 6% on $55,000; which sum the community could borrow for the purpose of reducing the grade to a level, pay the interest and be no worse off financially, and have a good road besides.

849. Profit of Decreasing Length.—The Profit arising from the elimination of any unnecessary length may be stated as follows:

(1) Saving in time.

(2) Reduction in wear and tear of horses and equipment.

(3) Saving the cost of maintenance of such unnecessary portion.

(4) Reduction in the cost per ton-mile of haulage.

(5) Saving by the return of the land previously occupied by the road to other and perhaps more remunerative uses.

(6) The decrease in the working time of the horses will permit of a slight increase in the load.

The saving in the above items will vary directly as the distance saved.

As an example take a level road 5 miles long and, neglecting the saving in time and rental value of the land saved, and increase of load, what will be the effect of decreasing its length one mile?

(1) Saving of the annual maintenance of 1 mile.

(2) Reduction of the time required in travelling over the road, thus permitting persons who make several daily trips to make an extra trip per day at the same cost for driver and horse-feed and with no extra fatigue to the horses.

(3) Saving in wear and tear of horses shoes, harness, and vehicles.

(4) Saving in the ton-mile cost for haulage.

Assuming observation of the traffic to show that 100 teams drawing average net loads of 2500 pounds use the road daily, and that the cost per ton-mile is 20 cents, therefore the annual tonnage = 33,480 tons, and the total annual cost of haulage per ton-mile = $6696.

Summing up the items, we have:

Saving of maintenance 1 mile............................	$50.00
33,480 ton-miles, at 20 cents..............................	$6696.00
	6746.00

Which is equivalent to the interest at 6% on $112,433, which sum could be borrowed to make the improvement.

850. Profit of Improving the Surface.—The benefits accruing from this improvement are a general reduction in the cost of haulage and wear and tear. The smooth, hard road-surface enables the same power to haul a greater load with the same and even less fatigue than it can on a rough surface.

The less the resistance to traction the greater the load, and the greater the load the sooner will the produce be marketed. Besides the wear and tear on a smooth surface is not one third that on a rough surface.

Assuming that it is required to know how much may be profitably expended in improving the surface of a level earth road one mile long, and that the observations show that it is used by 50 teams per day, each dragging when the road is in good condition a net load of one ton, and when in bad condition a net load of 1200 pounds, and that the cost per ton-mile when the road is in good condition is 18 cents, and when in bad condition 39 cents; that the road is in good condition for one half the year, and in bad condition for the other half; that the cost of paving and improving the road will be $7500 per mile,—then we have:

150 days, at 50 tons =	7500 tons, at 18 cents............ =	$1350.00
150 " " 27 " =	4050 " " 39 " .... =	1579.50
	11,550 "	
Cost of maintaining the earth road.....................		50.00
		$2979.50

$2979.50 ÷ 11,550 = 25.81 cents, average cost per ton-mile for haulage.

On a broken-stone road in its average condition and at all times throughout the year a team of horses will draw a net load of 3 tons at a speed of 3 miles per hour. If the cost of horses' labor, drivers' time, etc., be taken at 30 cents per hour, the cost per ton-mile will be 10 cents, or for the 11,550 tons annual traffic $1155; to which add for annual maintenance of one mile of road $350. The annual cost will therefore be $1605, which deducted from the former cost of $2979.50 leaves $1375, which, with money at 6% is equivalent to the annual interest on $22,916, which sum may be expended in improving the road-surface one mile long.

The annual loss occasioned by the waste of motive power on

unimproved road-surface is clearly shown by the above calculations. In the best condition of the earth road it required 50 teams to move 50 tons; on the improved surface but 17 teams are required to perform a like work, and the labor of the teams formerly required may be more profitably employed at other work. On the earth road in its worst condition it required two teams to move one ton; on the improved surface but one team is required to move three tons.

851. Any calculations made to ascertain the benefits accruing to a community from improved roads must necessarily fall far short of the truth, since no account can be taken of the saving in wear and tear of horses and vehicles, of the saving in time caused by the increased size of the loads, which thus decrease the number of days on which hauling must be done, thus allowing the time to be more profitably employed, or of the enhancement of the value of the land in consequence of the improved roads, or of the social advantages arising from their improvement.

CHAPTER XIX.

MAINTENANCE.—REPAIRING; CLEANSING; WATERING.

852. Maintenance.—The maintenance of a roadway is the keeping of it, as nearly as practicable, in the same condition as it was when originally made; the *repair* of a roadway is the work rendered necessary to bring it up to its original condition after it has become deteriorated by neglect to maintain it. Thus there is a wide distinction between the two operations, and when the comparison of costs is instituted errors are frequently caused by setting the repairs of one road against the maintenance of another or *vice versa*.

853. Necessity for Maintenance.—No matter how well made a structure may be, or how carefully the materials used have been inspected, the use of it will exhibit defects which it is almost impossible to guard against, such as variableness in the quality of the material and slighting on the part of the workmen. Moreover, every material, whether natural or artificial, is continually undergoing a process of deterioration by the action of the elements; this decay is hastened or retarded in proportion to the means employed and care bestowed to arrest it. The materials employed for pavements are not only subjected to the destroying action of the elements, but also to abrasion and concussion, which by themselves are powerful destroying agents. In view of these facts the continual presence of workmen engaged in repairing pavements must not in all cases be considered as evidence of defective construction or improper materials, but as an honest endeavor by those in charge of the highways to preserve the surface in good travelling condition.

854. The essential requisite to the preservation of a good surface is eternal vigilance on the part of the roadway keepers. If a depression appears in consequence of settlement, defective material, or other causes, it must be at once eliminated; if not, it will be

quickly deepened and enlarged by each succeeding vehicle, and will thus become an obstacle to safe travelling.

855. Good Maintenance comprises:

(1) Constant daily attention to repair the ravages of traffic and the elements. The character and quantity of these repairs will vary with the character of the pavement and the manner of its construction. With granite blocks laid on a concrete foundation they will be the least, with broken stone they will be the greatest; the other materials, as wood, asphalt, and brick, lying between.

(2) Cleansing, i.e., removing the detritus caused by wear, horse-droppings, and other refuse finding its way into the streets.

(3) Watering to lay the dust.

856. Systems of Maintenance.—Three systems of maintaining pavements are in vogue:

(1) By contract, at a fixed price per square yard per annum for a fixed period. Under this method asphalt pavements are maintained in both the United States and Europe. Wood pavements are also maintained under this system in Europe, but rarely in America. The form of contract under which this system is carried out in Europe is given in Articles 214 and 265. The advantage of this system is that of having some one admittedly responsible for the condition of the pavement. Its defects are (*a*) the difficulty of determining the exact condition the pavement is in at the expiration of the contract. (*b*) It is an extremely costly system.

(2) By independent contracts for the labor and materials, the tools and supervision being furnished by the city.

(3) By men in the employment of the city, materials, etc., being purchased in the open market. This is the system adopted by the city of Liverpool, and the excellence of that city's pavements needs no comment.

857. Maintenance of Country Roads.—When a country highway is finished and thrown open to traffic, it cannot be left to take care of itself; if it is, it will soon deteriorate and become bad. It is to the thorough appreciation of this fact that the excellence of the European roads is due. Upon its completion a system of maintenance must be instituted. Three systems are in vogue: (*a*) By contract with private parties. (*b*) Personal service by the rural population. (*c*) By men permanently employed for the purpose by the community.

(*a*) The contract system is unsatisfactory, from the difficulty of getting a proper observance of the terms of the contract from the contractor or his employers.

In Austria during the last century experiments were made with the letting of the maintenance of the state roads to private parties, which experiments proving unsatisfactory, caused the government to take the work in hand, and it has adhered to this practice up to the present day, with a short interruption in the years 1858–1861, during which time the keeping of the roads was again let by contract, and again gave unsatisfactory results.

(*b*) The personal-service or labor-tax system is not applicable to the maintenance of improved roads. In fact, it is not applicable to any class of roads; it is unsound in principle, unjust in its operation, wasteful in its practice, and unsatisfactory in its results.

(*c*) By men permanently employed for the purpose by the community. This system has been adopted by France, Germany, and nearly all European countries. Its advantages are many. The men so employed become familiar with the peculiarities of their sections and with the best way to deal with them, and good men soon learn to take an interest in the road which it is their business to keep in order. "It is in vain to expect the same skill or industry from men employed by the job, or having no interest in the goodness of the road, or in making the most of the means at their disposal."

858. The maintenance or keeping of the road in proper order consists of:

(1) The daily removal of the detritus either in the form of dust or mud, the horse-droppings and other rubbish.

(2) The filling of ruts or depressions.

(3) The cleansing out of the ditches, catch-basins, and water-courses.

(4) Watering the surface in dry weather.

The disintegrating action of the weather and the friction of the traffic produces dust; this dust renders the road heavy for traffic and annoys passengers and horses. If rain falls, the dust is converted into mud. A well-swept road produces no mud after a rain, at least not for several days. However, if the humidity continues, the road-surface becomes at first sticky and finally is covered with mud. Mud makes the tracks of wheels apparent; other vehicles

follow in them, and after a while ruts are formed which injure the road. Thus it is essential that the dust and mud be removed from the road-surface. The dust may be removed by sweeping, the mud by scraping. These sweepings and scrapings should not be left on the sides of the road to be redistributed by the first wind, but should be immediately removed: they might be utilized by the farmers as an adjunct to their manure-pile.

(1) The best time for sweeping is early in the morning before the dew has dried; besides, there is less inconvenience to the traffic at that time.

The removal of dust and mud may be effected either by brooms and hand-scrapers or by mechanical sweepers and scrapers drawn by horses. In the rural districts the former will be most suitable, while in the vicinity of towns the latter will be most economical.

(2) Daily attention must be given to the making of slight repairs such as filling ruts and depressions; for, however well the materials may be laid and rolled, the traffic will search out the places which are weak or have escaped the full pressure of the roller.

(*a*) All ruts should be at once filled. If there are three parallel, the centre rut should be first filled. The traffic is thus slightly diverted, as a horse will avoid new metal.

(*b*) Depressions or hollows should be filled at once. The surface of the road should never be allowed to lose its regular section.

(*c*) If the surface of the road where these patches are to be placed is very hard, it must be loosened up with the pick.

(*d*) Water lodging in a depression should not be let off by digging a trench with the pick-axe to the side of the roadway. The depression should be filled up.

(*e*) All loose stones should be picked off at once and stored for use in filling hollows. If allowed to remain, they are not only dangerous to horses, but are liable to be crushed or to be forced through the skin of the roadway, thus causing damage.

(3) At all seasons of the year the gutters should be kept free from mud and rubbish of all sorts, and anything that impedes the free discharge of the rain-water from the road must be removed.

The ditches and culverts should be well cleaned out in advance of the spring and fall rains. In northern localities, where snow lies for some time, the outlets of all ditches and culverts should be

opened and cleaned out before the spring thaw sets in. In the fall all weeds and grass in the ditches should be cut, and the culverts and water-outlets left in good shape for the winter.

All bridges should be examined at least twice a year.

All structures such as bridges, culverts, and drains should be numbered, the numbers being legibly painted on some prominent part; and a book should be kept in which the dates and condition at periodical inspections are entered.

Retaining-walls should be examined and repaired at least once a year.

Guard-stones should be reset immediately they become displaced.

Parapets, mile-stones, and guide-posts should be periodically examined, repaired, and reset.

(4) Watering to lay the dust is essential in summer and occasionally in winter. In summer, during the dry hot weather, the road-surface becomes extremely brittle and then should be watered, the dust and refuse having been first removed.

Sometimes, in winter especially, after frost the road gets very sticky and picks up freely under passing wheels. It should then also be watered and all slush and mud removed. When the dust is regularly removed from a road it does not require so much watering in dry weather as it otherwise would.

A road should never be watered unless it really needs it, as too much water is injurious and it increases the wear from traffic.

The most common method of watering a road is that of carrying the water in barrels mounted on wheels or vehicles specially constructed for the purpose and distributing it therefrom through a perforated pipe.

859. Amount of Water Required.—Mr. E. P. North found the amount of water necessary to keep macadam roads in the vicinity of New York from becoming dusty to be at the rate of 71.3 cubic feet per 1000 square yards applied twice in a day, or say 143 cubic feet per day. In very hot or breezy weather this was not quite enough.

On the Telford roads in New York 25 cubic feet applied four times a day are necessary per 100 square yards, or about 100 cubic feet per day.

One water-cart holding 79 cubic feet waters 35,000 square

yards four times a day, keeping it free from dust except during windy weather.

860. Cost of Maintenance.—The cost of maintenance is very variable, being principally dependent upon the degree of perfection with which the road has been constructed, but largely influenced by the employment of a sufficient number of skilled laborers to maintain the surface in proper condition under skilled supervision.

The cost of maintaining the roads of France varies from $60 to $500 per mile, with an average of $150, of which about half is for labor and half for materials.

The following table gives the cost per annum per square yard for the maintenance of macadamized streets in different localities:

Bristol, Eng.	8 to 24 cents
Charing Cross, London*	100 "
Glasgow, Scotland	17 "
Leeds, Eng	20 to 26 "
Liverpool, Eng	24 " 36 "
Manchester, Eng	12 " 40 "
Paris, France	19 " 258 "
Toronto, Can	24 "
Belgium	4 " 10 "
Germany	20 " 80 "

* Now paved.

861. Repair.—When the thickness of the covering is so reduced that it is necessary to re-cover it with stone, let it be done in sections as large as convenient. The stone should be spread and rolled in the same manner as directed for building. As a rule, in re-coating, the thickness need not be more than two or three stones. The periods at which re-coating will be required depend upon the quantity of the traffic, and will vary from three to five years.

862. Organization of Road Force.—For the proper care of a roadway an adequate amount of skilled laborers permanently employed is necessary. This labor should be employed by the community, and be under the direct orders and supervision of the county engineer. The force should be arranged as follows: county engineer, inspectors (assistant engineers), chief foreman, foremen, laborers.

The number of men required will depend upon the amount of the traffic. With light traffic one laborer will be required to every

4 miles; with heavy traffic and a wide road one man will be required to every mile. In the spring and fall extra help will be required; the extra men should be directed by the permanent roadman on each section, whose knowledge of his section will enable him to employ them to the best advantage.

Chief Foreman.—There will be required one chief foreman for every 100 miles of road. His duties shall be to superintend the entire road management under direct orders from the County Engineer, received either from himself or his assistants. He shall have no power to engage or discharge any foreman without first reporting to the engineer, but shall have full authority over the laborers. He shall set out and direct all work for the foremen, shall OK the foremen's requisitions for tools, supplies, horse-labor, etc. He shall under no circumstances purchase tools, materials, or employ special labor unless the requisition therefor is signed by the engineer, in cases to avert an accident or to save expense alone excepted. He shall walk the district in his charge as far as practicable, and carefully take and keep notes of work required to be done, inspect all bridges and structures. He shall examine the foremen's book and see that all accounts are properly entered.

He shall keep an order and tool account, a material, team, and general expenditure book, also a careful diary of his day's doings. He shall work the same hours as the workmen, and do his utmost to skilfully manage and check all extravagance, filling up any spare time in doing necessary work. In the absence of any foreman he shall take his place and direct the work until new arrangements can be made. He will have charge of the steam road-roller and be responsible for the economical working of the same.

Foreman.—The best men obtainable should be employed for this work. They should have about ten miles of ordinary country road to superintend, varying, of course, very much with the traffic; they should live as near as is practicable to the centre of their sections. They should not be changed from one section to another, but be retained permanently in the same section.

Each foreman should be supplied with a blank diary, in which he should write up every day the work he is engaged upon; each page so written to be initialed by the chief foreman. This diary should always be in his possession while on the road, and should

always be ready for examination by the inspector or engineer, who will note in it the date of examination. The foreman will also be supplied with a time-book in which to keep his own and his men's time; also with an account-book in which he will note the reception and weight of all material, keep an account of all tools, extra labor, team-hire, blacksmith and all other accounts of his section.

The foreman shall take all necessary instructions from the chief foreman, and in his absence all orders from the inspector or engineer must be promptly carried out. They shall work themselves and see that the work is properly carried out on their section. They shall have no power to discharge or engage any workman without first reporting the matter to the chief foreman.

Tools.—Every foreman should be supplied with the following tools for the use of the men under him and himself: shovels, pick-axes, spades, hoes, rakes, rammers, wheelbarrows, brush-hooks, axes, scrapers, brooms, stone-sledges, stone-hammers, straight-edge, level, line.

The tools should be repaired by the nearest blacksmith, under contract for a year or more at schedule rates, and before any tools are repaired the foreman shall give a written order to the smith and preserve a duplicate himself.

Whether the county shall purchase a stone-crusher or not will depend upon circumstances, whether stone is to be had in the county or not, or whether it can be purchased cheaper.

Roller.—The proper maintenance of a road cannot be carried out without the employment of a roller. If the extent of the road will not warrant the purchase of a steam-roller, a horse-roller should be secured. Whichever kind of roller is used, its weight should not be less than 4 tons and need not exceed 10 tons; the weight per inch of width is more important than the gross weight of the machine.

Team-labor and Materials.—All team-labor and materials should be supplied under contract. The chief foreman of the section will keep the time of all horse-labor and give time-checks for the same. If stone is purchased, it should be bought by weight, and each load delivered should be weighed on a public weighing machine, and the weight-check delivered to the foreman receiving

the material, who in turn will deliver to the carter a receipt in the form furnished for the purpose.

Accounts.—Accounts of all kinds should be sent to the County Engineer direct as soon as the work or contract is complete, and no account should under any circumstances be passed unless accompanied by the necessary order for the work being carried out.

Requisitions for tools, etc., should be sent in by the foreman at a fixed date in each month, and a date be fixed for their issuance.

Snow.—When snow has fallen heavily or is drifting, the road-guard must shovel it off the road so as to keep a track open. If he is unable to do this with the assistance of hired laborers, he must make requisition for extra help. If, on account of continued drifting, the road cannot be kept open, the travel may be temporarily led over the adjoining fields, care being taken to mark the location of the temporary road by poles and wisps of straw or tree-branches. When the weather permits sleighing for some time, loose stones and gravel liable to cause accidents are to be removed, and bare spots are to be covered with snow.

When thaw sets in, all snow and ice on the roads must be speedily removed.

County Engineer.—The County Engineer with the aid of his assistants will take direct management of all the roads, set out all work and give directions to the chief foreman, and, in general, superintend the carrying out of all work, make plans and prepare estimates for all materials, keep all accounts and perform all incidental duties.

Storage and Delivery of Broken Stone.—Depots or spaces for the storage of the broken stone should be provided along the sides of the road; these depots should be close enough together for the roadmen to wheel out the stone to the intervening portions of the road.

The contractor should be required to deliver the broken stone at each of these depots at such times and in such quantities as the engineer may direct. The stone heaped up at the depots should not be allowed to encroach upon the road or interfere with the gutters; one or two cubic yards will be a sufficient quantity to have at each depot. A convenient size for the stone-heaps will be 6 feet long, 3 feet wide, and $1\frac{1}{2}$ feet high. Such a heap will contain 1 cubic

yard, and the quantity so stored can be ascertained by measurement at any time.

863. Records.—It is very desirable that those in charge of roads should adopt some form of record, showing plainly the cost of materials, of labor, and of any miscellaneous expenditures connected with the maintenance of roads. Comparisons of the total cost of different roads, and of the proportion of expenditure for materials and labor, and for other things, would be facilitated, and a step would be taken towards gathering statistics relating to road-maintenance which are at present wanting in both America and England.

864. Instructions to Roadmen (published by the Road Improvement Association of No. 57 Basinghall Street, London, E. C.) will be found useful to roadmen, and are therefore submitted *in extenso:*

(1) Never allow a hollow, a rut, or a puddle to remain on a road, but fill it up at once with chips from the stone-heap.

(2) Always use chips for patching, and for all repairs during the summer months.

(3) Never put fresh stones on the road if by cross-picking and a thorough use of the rake the surface can be made smooth and kept at the proper strength and section.

(4) Remember that the rake is the most useful tool in your collection, and that it should be kept close at hand the whole year round.

(5) Do not spread large patches of stone over the whole width of the road, but coat the middle or horse track first, and when this has worn in, coat each of the sides in turn.

(6) Always arrange that the bulk of the stones may be laid down before Christmas.

(7) In moderately dry weather and on hard roads, always pick up the old surface into ridges six inches apart, and remove all large and projecting stones before applying a new coating.

(8) Never spread stones more than one stone deep, but add a second layer when the first has worn in, if one coat be not enough.

(9) Use a steel-pronged fork to load the barrels at the stone-heap, so that the siftings may be available for "binding" and for summer repairs.

(10) Never shoot stones on the road, and crack them where they lie, or a smooth surface will be out of question.

(11) Go over the whole of the new coating every day or two with the rake, and never leave the stones in ridges.

(12) Remove all large stones, blocks of wood, and other obstructions (used for diverting the traffic) at nightfall, or the consequences may be serious.

(13) Never put a stone upon a road for repairing purposes that will not pass freely in every direction through a 2-inch ring, and remember that still smaller stones should be used for patching and for all slight repairs.

(14) Recollect that hard stone should be broken to a finer gauge than soft, but that the 2-inch gauge is the largest that should be employed under any circumstances where no steam roller is employed.

(15) Never be without your ring-guage. It should be to the roadman what the compass is to the mariner.

(16) If you have no ring-gauge, remember MacAdam's advice that any stone you cannot put easily into your mouth should be broken smaller.

(17) Use chips, if possible, for binding newly-laid stones together, and remember that road-sweepings, horse-droppings, sods of grass, and other rubbish, when used for this purpose, will ruin the best road ever constructed.

(18) Remember that water-worn or rounded stones should never be used upon steep gradients, or they will fail to bind together.

(19) Never allow dust or mud to lie on the surface of the road, for either of these will double the cost of maintenance.

(20) Recollect that dust becomes mud at the first shower, and that mud forms a wet blanket which will keep a road in a filthy condition for weeks at a time, instead of allowing it to dry in a few hours.

(21) See that all sweepings and scrapings are put into heaps and carted away immediately.

(22) Remember that the middle of the road should always be a little higher than the sides, so that the rain may run into the side gutters at once.

(23) Never allow the water-tables, gutters, and ditches to clog up, but keep them clear the whole year through.

(24) Always be upon your road in wet weather, and at once fill up with "chips" any hollows or ruts where the rain may lie.

(25) When the main coatings of stone have worn in, go over the whole road, and, gathering together all the loose stones, return them to the stone-heap for use in the winter to follow; for loose stones are a source of danger and annoyance and should never be allowed to lie on any road.

865. The French System of Highway Maintenance.—The system of highway maintenance adopted by the French, whose roads are unexcelled by any is as follows:

The roads are divided into national, departmental, military, and vicinal or country cross-roads.

The national roads are maintained entirely at the expense of the public treasury; the departments provide for the second class of roads, and also partly for the military roads; the local cross-roads are maintained by the communes, or when of higher importance by the departments.

The national roads aggregate upwards of 23,180 miles in length, of which 1632 miles are paved like a street. These roads average in width 16 metres or 52 feet 6 inches, of which 19.68 feet is for the wheelway, 19.68 feet for the sidewalks, and 13.12 feet for the ditches and embankment slopes. The department roads are not quite so wide, their average width being 39 feet. The aggregate length of the latter is about 29,167 miles. The military roads number 28, and are about 932 miles long in all. They are chiefly in the west of France, laid out after the last insurrection of Vendée. The sum of about $6,800,000 is yearly expended in making new roads or repairing old ones, and $32,000,000 is expended for maintenance and inspection.

The cross-roads are managed by a special branch of the department of the Minister of the Interior, a branch which employs about 3000 inspectors and 42,000 workmen, specially charged with the duty of keeping these roads in repair. In 1872 these cross-roads aggregated 338,273 miles in length and covered a surface of about 915,000 acres. To the very considerable sum which the communes must apply to the extension and repair of these country roads, the government used to add a yearly grant of $2,300,000; but since 1873 this sum has been reduced to $1,150,000 annually.

The care of the national roads is a large part of the duties of the "Engineers of Bridges and Roads" (*Ingénieurs des Ponts et Chaussées*) and belongs to the portfolio of the Minister of Public Works.

In each department there is appointed by the Minister of Public Works an engineer-in-chief, who has the direction and responsibility of the work of maintenance of such portion of the national roads as lie within that department. He is also placed in charge of some other work in that department; either of railroads, canal or river improvements, or the care of the seaports, if such lie in that department.

Sometimes he is also in charge of the departmental roads, and in a few cases of the county roads as well. Under him are several Engineers-in-ordinary (*Ingénieurs ordinaires*), who are employed only in a certain section of the department; each one having charge of the work in an arrondissement.

There they direct the repairs according to the general plans of their chief, but at the same time they are allowed considerable latitude to display their ability or originality and follow out their own ideas in the details of the work. Their duties require them to visit carefully at least four times a year, oftener if necessary, every road confided to their care.

The next grade below the engineers-in-ordinary is that of Conductor or Assistant Engineer.

The conductor has a subdivision comprising a length such that he may be able to inspect it in detail at least twice each month and still have sufficient time to attend to the other requirements of the service with which the chief is charged, i.e., of bridges, railroads, canals, seaports, etc.

The supervision comprises usually from 25 to 50 miles of road, according to the distribution and the complexity of their maintenance, and of other details connected with them. The conductor makes semi-monthly inspections of the roads under his charge, and, further, he makes his tour of inspection on foot.

He gives orders to the foremen of the different gangs at work along the roads. He keeps a record of their work, to see that they do a proper amount. If any have been guilty of neglect, he may recommend to his chief that they be punished.

Following each regular inspection he forwards a written report

to the engineer in charge of that division. He keeps the accounts for his division. He is consulted by the engineer in case of the receipt of any petition or other affairs upon which his accurate knowledge of the division would make him capable of giving information or advice.

If any surveys are to be made, he makes them. He also inspects all road material, all of which is furnished by contract, and has immediate charge of the construction of all new work.

The engineer can give no order to the laborers without giving it through the conductor.

In districts where there is much to do he is aided by a second assistant engineer.

This is the grade held by the younger engineers, who have charge of the drafting and clerical work in the chief-engineer's office, and also assist in the outdoor work when there is a press of it.

It is from the ranks of these latter that by promotion the corps of assistant engineers or conductors is kept up to the required number. Their promotion is made on their successfully passing examinations for that purpose.

Under the conductor comes the road laborer or cantonnier. The road laborers are divided into squads of five or six. Each one is in charge of an overseer, chosen from one of their number.

Each of the road laborers has charge of a length of road varying from $1\frac{1}{2}$ to $2\frac{1}{2}$ miles, depending upon the condition of the road, the amount of circulation, and the method of maintenance, which would depend upon the nature of its construction.

When there happens to be much work to be done at once, a few laborers by the day are hired to assist, but they are reduced to the least possible number.

If there is to be work that will require extra laborers for a considerable length of time, they organize another road gang, so that the work will be done by regular hands.

866. Regulations for Cantonniers (Road Laborers).

Definition of the Work of Cantonniers.—The cantonniers are charged with the manual labor connected with the daily maintenance of the roads, over a definite length of road, called a canton.

They must obey, in everything relating to their work, the engineers, foremen, and other agents of the administration of roads and bridges.

Nomination of Cantonniers.—The cantonniers are nominated by the prefect, from a list submitted to the chief engineer, containing three times, or at least twice, the number of candidates required to fill the vacancies. They are dismissed by the prefect on the advice of the chief engineer.

Conditions of Admission.—To be nominated a cantonnier it is necessary (1) to have fulfilled the laws relating to service in the army, and to be not more than 45 years old; (2) not to be subject to any infirmity which may hinder daily and diligent labor; (3) to have worked on the construction or repair of roads; (4) to have a certificate of good conduct from the mayor of the commune or the subprefect of the arrondissement.

Candidates who can read and write will be preferred.

Chief Cantonnier.—The cantons of the roads in a department shall be grouped in districts containing at least six cantons. The six cantonniers will constitute a brigade; one of them shall be chief cantonnier; he must be able to read and write, and shall be chosen from the cantonniers distinguished for zeal, good conduct, and intelligence.

The chief cantonniers shall have a shorter length than other cantonniers, so that they may be able to attend to special duties allotted to them. They shall accompany the foremen in their rounds, and note the orders which may be given by the cantonniers of their brigade, and see that the orders are carried out. They shall accordingly go over the whole extent of their district at least once a week, varying the days and hours of their visits, to satisfy themselves of the presence of the cantonniers, and to direct them in their work; they shall report to those under whose orders they are more particularly placed, and shall furnish to the engineers all the information that may be required of them.

They may be temporarily employed in superintending and keeping account of the works of re-dressing the paved causeways, and in directing itinerant gangs of workmen.

Distinctive Marks of Cantonniers.—Cantonniers shall wear a blue jacket and a leather hat, round which shall be a band of copper 0.28 m. long and 0.055 m. broad, with the word "cantonnier" cut out in it. The chief cantonniers shall wear besides on the left arm an armlet of the prescribed pattern.

There shall be given besides to each man a mark consisting of

a staff 2 metres long, divided in decimetres, shod with iron, and furnished at the top with a strong iron plate 0.24 m. wide and 0.16 m. high, on each side of which shall be shown in letters 0.08 m. high the number of the canton. This mark must always be set up on the road at less than 100 metres from where the cantonnier is at work.

The Work of the Cantonniers.—The work of the cantonniers consists in maintaining and repairing the roads daily and constantly, so that they may be dry, clean, and smooth, safe in times of hard frost, and of a satisfactory appearance at all seasons.

To effect this, they must, subject to the orders and instructions which may be given them in case of need:

(1) Insure the flowing off of water by cleansing the gutters, pipes, etc., by making small drains for the purpose wherever they may be necessary, taking care that these drains should never be made in the body of the road.

(2) At suitable times open and maintain the ditches, regulate the sides, throwing the surplus earth on the neighboring ground, if there is no objection, or putting it together to facilitate its measurement or removal.

(3) Remove as soon as possible with a scraper or shovel all liquid or soft mud from the whole breadth of the road, even if there be neither hollows nor ruts, and collect the mud in regular heaps on the sides to be measured, if there is room for it there.

(4) Spread the mud, when dry, on the sides which have lost their shape or have a slope of more than 1 in 25 from the road, and throw the surplus on the neighboring fields, if not objected to.

(5) At the approach of winter redouble attention to all that is prescribed in the two preceding paragraphs, to prevent lumps of frozen mud.

(6) In dry weather remove the dust and deposit it on the sides.

(7) Clear away the snow from the whole breadth of the road, or at least from the middle, particularly at places where it accumulates and obstructs the traffic; throw it immediately on the neighboring fields if possible, or collect it in heaps on the sides, so as to show drivers of vehicles where the road is.

(8) Break and remove ice from the road, and scatter sand and rubble, especially at the sides and at sharp turnings.

(9) Also break the ice in the ditches and remove it where it accumulates, so as to threaten flooding of the road in the thaw.

(10) In the time of thaw assist the flowing off of the water and remove pieces of ice, mud, and dirt, so that the effects of the thaw may prejudice the traffic and road as little as possible.

(11) Collect, break, and stack in separate heaps and in a particular shape all loose stones, and those projecting or only just showing if too large, and those near in the neighboring fields which can be used for the purposes of the road. Break the materials intended for maintenance, if the breaking is not done by the contractor.

(12) Cut or dig up thistles or other weeds, especially before their flowering season.

(13) Clear away loose stones for the road and everything which may hinder the traffic.

(14) Clean and clear away earth, plants, and extraneous matters from the plinths, string-courses, and parapets of bridges, etc.

(15) Look after the preservation of mile-stones, sign-posts, and bench-marks on the road.

(16) Cultivate and look after plantations belonging to the State, see to their preservation and to that of plantations of private owners, straighten provisionally all young trees bent by the wind, and do generally all that the welfare of the road demands, conformable to more particular instructions given by the engineers of the district for carrying out the above general orders.

Employment of Materials.—On roads in a state of repair the road laborers shall conform to the following rules for employment of materials.

The materials shall be made use of as they are required, always choosing damp weather for their employment, avoiding wholesale coating and throwing down stones at random.

To proceed regularly, care should be taken to observe in time of rain the hollows and tracks of vehicles, which perceptibly alter the shape of the road.

These worn parts should be cleaned and picked, particularly at the edges, but only to the depth necessary to insure the binding of the materials. The materials arising from the picking should be cleared of earth and broken if necessary before being used.

The filling up of the hollows or wheel-tracks should be effected

with the débris and with the necessary quantity of new material received through the engineer. It must be carefully beaten so as to incorporate it with the lower layer, and then made to conform to the contour of the road. The parts thus restored should be maintained with particular care until they are completely consolidated.

With respect to roads which are not in a good state of repair, but which nevertheless are open for traffic, one should endeavor to keep them in as good a condition as possible by employing, with the care which has just been indicated, the materials available.

All large or projecting stones should be taken out, as they cause damage, and they should be broken to a proper size before being used again.

The coatings more or less extensive to be made on worn roads will be prescribed by the engineer, who will also decide on the materials to be used. The hollows and ruts to be filled up must first be cleared of mud and earth, and their surface then picked to a depth of from 4 to 5 centimetres ($1\frac{1}{2}$ to 2 inches). The materials should not be spread except in layers of from 5 to 6 centimeters (2 to $2\frac{1}{2}$ inches), which should be carefully beaten and consolidated.

Task-work to be performed.—To stimulate and maintain the activity of the cantonniers, the engineers, inspectors, and foremen shall assign them work to be performed in a given time, whenever local circumstances permit it. A summary of information on these tasks shall be entered in that part of the cantonnier's book reserved for the instructions of the service.

Work thus prescribed shall be one of the principal objects of supervision by the immediate head of the cantonniers, as well as by the mayors and road commissioners.

Determination of Working Hours.—From the 1st of May to the 1st of September the cantonniers shall be on the roads, without quitting them, from 5 o'clock in the morning to 7 o'clock in the evening. The rest of the year they shall be there from sunrise to sunset. They shall take their meals on the road at hours fixed by the chief engineer. The total duration of meals shall not exceed two hours, but during great heat it may be prolonged to three hours.

Removal of Cantonniers.—Cantonniers may be removed either singly or in brigades, when the needs of the service imperatively

require it, to points indicated to them. These displacements shall not take place except under an express order from the engineer.

Compulsory Attendance of Cantonniers in time of Rain, Snow, etc.—Rain, snow, or other inclemency of the weather shall not be a pretext for the absence of cantonniers; they must in such times redouble their zeal to prevent damage and keep the road in good condition for the whole extent of their cantons. They are, however, authorized to make themselves fixed or portable shelters which shall not interfere with the public way or adjoining property, but which must be in sight of the road and less than 10 metres off, so that the presence of the workmen can always be ascertained.

Gratuitous Assistance to Travellers.—Cantonniers must render gratuitous aid and assistance to drivers and travellers, but only in case of accidents.

Surveillance over Breaches of Highway Law.—To prevent as much as possible breaches of highway law, the cantonniers shall warn travellers and occupiers of the adjoining lands who may be disposed to commit them. They shall consequently keep an eye on repairs, building, deposits, encroachments, and planting which may take place without leave on the highway. They shall report any such breaches to the surveyor, either when he makes his rounds, or at once by letter or by message through the chief cantonnier.

Tools with which Cantonniers must be provided.—Every cantonnier shall be provided, at his own expense, with a wheelbarrow, an iron shovel, a wooden shovel, a road-pick, an iron road-scraper, a wooden road-scraper, an iron rake, an iron crowbar, an iron sledge-hammer, and a line 20 metres long.

The head cantonniers must besides be provided with three boning rods (rods in the form of a T much employed in European countries to range in grades, etc.), with a level graduated to indicate gradients, and with a double metre measure.

Tools of a Particular Kind to be furnished by the Administration.—Each cantonnier shall be entrusted with an iron ring 6 centimetres ($2\frac{1}{2}$ inches) in diameter, so that he may ascertain if the stones which he has to spread on the road have been broken according to the specifications.

Providing Tools in advance to Cantonniers.—Cantonniers who have no means of procuring them can have any tools they require

supplied in advance. The repayment of the cost of these tools will be insured by the administration by stoppages, which, except in cases of dismissal, shall not exceed one sixth of the monthly salary.

Keeping Tools in Repair.—Cantonniers shall keep their tools in a good state of repair. If they become negligent in this respect, they will be repaired by the administration, and the expenses will be repaid in the same manner as for new tools.

Tools must not be taken to be repaired during working hours. Excuses for absence based upon the necessity of getting tools repaired will never be accepted.

Cantonniers' Books.—Every cantonnier will be provided with a book suitably ruled and headed, in which he will make notes on the work and conduct of the laborers, any orders and instructions given them, and information of the work which has been assigned to them. It must be presented by them to the agents charged with the supervision of the road, every time they are required to do so, under penalty of the stoppage of a day's pay for every time they neglect to produce it, or three days' pay in the case of having lost it.

Means of Verifying the Absence of Cantonniers.—The absence and negligences of cantonniers will be verified by the engineers and the agents of the administration employed under their orders, who will make a note of them in the books just spoken of. Absence can also be verified by gendarmes on their rounds, by mayors of the parishes in which the cantons are situated, and by road commissioners.

Leave of Absence at Harvest-time.—At harvest-time, when the road is in good condition, cantonniers can obtain leave of absence from the engineer-in-ordinary, when authorized by the engineer-in-chief. They will receive no salary while on leave of absence, at the expiration of which they must return punctually to their posts or they will be immediately superseded.

Surrender of Book and of Distinctive Badges on Dismissal of a Cantonnier.—When a cantonnier is dismissed, he must surrender to the engineer his book, his staff, his ring, and the distinctive badges which he wears on his arm and cap. Failing to do this, double the value of these articles will be retained from that which is due to him for salary at the time of his dismissal.

Classification and Salary of Cantonniers.—Cantonniers of

each department will be divided into three classes of equal number, whose salary, for each class, will be fixed by the prefect, on the proposal of the chief engineer.

The classification will be made each year by the chief engineer, on the report of the engineer-in-ordinary, and according to the services of the cantonniers during the preceding year.

The chief cantonniers will be divided into two classes, likewise of equal number.

Their salaries will be fixed, like those of the ordinary cantonniers, by the prefect, on the proposal of the chief engineer.

The cantonniers receive from \$10 to \$20 per month, and the chief cantonniers receive 20% more.

Indemnity for Removal.—Cantonniers who leave their cantons by order of the engineer will receive an indemnity of one fifth more than their salary, and three fifths for every day they sleep out.

No indemnity for removal will be allowed to head cantonniers except when they go out of the district of their brigade. In this case, the indemnity to which they are entitled will be regulated in the same way as those which are paid to ordinary cantonniers.

Annual Gratuities.—Every year, on the report of the engineer-in-chief, the prefect may grant to the most deserving cantonnier in each district of the engineer-in-ordinary, a gratuity, which shall not exceed a month's salary.

A similar gratuity may also be awarded to that one of the chief cantonniers of the department who shall have rendered the best service.

Fines on Account of Absence.—Every cantonnier who shall not be found at his post by one of the agents having a right of supervision on the road, shall be subject to a fine of three days' pay for the first time, of six days in case of a second offence, and be dismissed the third time.

Those who, without being absent, shall not have done enough work during the month, or who have neglected the duty entrusted to them, will be fined enough to pay for repairing any damage resulting from their negligence.

A part of these fines may be granted by the engineer-in-chief, on the report of the engineer in ordinary, for the benefit of those cantonniers who by their zeal and work have deserved encouragement.

867. The system described above, while employed throughout France for the maintenance of the national roads, is applied to all the other roads in but 27 of the 87 departments.

In three departments the engineer-in-chief has, it is true, the direction of the work, but has under him a different corps of engineers or commissioners to superintend the work upon the county or vicinal roads.

In 57 of the departments a commissioner appointed by the Minister of the Interior has charge of the county or vicinal roads. His corps comprises commissioners or trustees in the arrondissements and cantons who are appointed by the prefect of the department.

The ordinary vicinal roads are in the charge of the mayors of the communes. The direct agents are inspectors, who are charged with the duty of watching this work, and are responsible for its proper execution.

Inspectors.—The chief inspector is under the direct authority of the prefect, and he has charge of all the vicinal roads of the department, and all the sub-inspectors are under his orders. He executes the laws and regulations prescribed, and the inspectors of arrondissements have similar power in their own districts. The chief inspector may, when he deems fit, order that certain operations shall be carried out under agents directly under his control.

Under the law of 1836, the appointment of inspectors of all grades lay with the prefect, who might, if he so chose, transfer the control of the roads to the government corps of engineers. This right of option was taken from the prefect by the law of 1866, which included among the duties and privileges of the Council General of the department the right to designate to what parties should be confided the execution of work upon vicinal roads. The laws of 1871 confirmed this right and extended it to departmental roads, so that to-day the nomination, organization, and control of the staff in charge of department roads of all classes is the exclusive right of the prefectural authority, without restriction.

The inspectors are divided, ordinarily, into inspector-in-chief, inspectors of arrondissements, and inspectors of cantons. They shall be French citizens and must be at least 21 years of age.

The law of 1836 prescribes that in each department there shall be a commissioner whose duty it shall be to examine candidates for the position; and when a vacancy occurs, it is the duty of the pre-

fect to announce the date of such examinations in his department, and send this notice to the prefects of adjoining departments. The Minister of the Interior is also notified of all such vacancies and changes.

The duties of the inspectors employed on the vicinal roads are to study the projects, arrange the plans, estimate the cost, and watch the execution of all road work, under the authority of the prefects and the mayors. Their pay is fixed by the Council General; and they are never to be remunerated by a percentage on work performed.

The Laborers.—The workmen for all main department highways and roads common to several communes are appointed by the prefect. The mayors of the communes name those employed on the ordinary vicinal roads; but as this appointment implies a fixed charge upon the commune, his action must be sanctioned by a vote of the municipal council.

Day's Work of Proprietors.—France has a system of working out road taxes, but it is carried out as follows: For work of this nature two periods are generally fixed in each year, ranging from one month to six weeks in length, each. The mayors of the communes fix the dates, and so arrange it that any work commenced can be finished in the specified time. And in connection with the inspector of the canton, the mayor also divides the workmen among the several roads and fixes the hours for beginning and ending work at each place. Five days before the date fixed the mayor sends to each laborer working under this system a notice requiring him to report at a certain day and hour, upon a certain road, for such work as may be there assigned to him. In case of sickness the laborer must make this fact known to the mayor within twenty-four hours after receiving his notice; and while the mayor may postpone the service required, this cannot be extended beyond the current year. As an unnecessary number of workmen at any one place leads to confusion and embarrassment, it is the duty of the mayor to detail at one time and on any one piece of work only a sufficient number of laborers to best accomplish a specified task without loss of time. If this labor is to be expended on a vicinal road of common interest to several communes, the prefect of the department designates the time and location of such work.

Each workman under this system carries to the place designated

such common tools as the mayor's notice may direct. Tools with which the farmers are not ordinarily supplied are furnished by each commune from the fund appropriated to public works. All beasts of burden must be harnessed, and all vehicles must have a driver, and the time of this driver is received as a full acquittance for the time of one man. Farmers may substitute for themselves, or members of their family, other men hired and paid for by themselves. These substitutes must be able-bodied men not less than 18 nor more than 60 years of age.

The length of the day's work is fixed in each department by a general rule issued by the prefect, and it varies according to the seasons of the year. This day's work cannot be divided, but must be furnished entirely by the laborer. In case of legitimate interruption by reason of bad weather, the laborers are bound to complete it at the earliest date possible. If the laborer fails to report at the hour indicated, or in any way fails to complete his legal day's work, the lost time must be paid for in money, and this fine can be legally recovered by the municipal receiver of taxes.

Works carried out on vicinal roads under the labor-tax system are under the direction and control of the mayor of the commune in which such roads lie. This functionary is assisted by the inspector in organizing his force and commencing work, and each day's work is preceded by a roll-call, compared with the list furnished by the mayor. If any laborer breaks any of the rules fixed for the conduct of the work, comes unprovided with the tools called for in his official notice, or in any way does not conscientiously perform the duty assigned him, he can be sent from the work, and the value of his services, or the proportionate part thereof, collected in money. At the end of each day's work the superintendent of works credits each laborer upon his official notice with the number of days and class of work done, and at the same time discharges the original requisition for labor. After the work is completed this accredited notice is signed by the mayor, and sent by him to the municipal receiver, and the latter makes the proper entry upon his books or register of *prestataires*.

In case a commune neglects or refuses to vote the number of days' work necessary on its roads in the proper time for performance, and the sub-prefect advises the prefect of this fact, it shall be the duty of the latter official to serve a special notice upon the

mayor of the defaulting commune demanding that he execute the required work within the specified time. This same notice also notifies the farmers that unless the work is well done in the time fixed, its value will be required from them, in money. This notice must be made public by the mayor; or in case of his refusal by a special agent of the prefect. All work of this character is done under the supervision of an inspèctor appointed by the prefect or sub-prefect, and the certificate of execution is delivered by the mayor on the certificate of this inspector. If the mayor refuses to do this, the certificate of the inspector himself is valid.

Task-work by Proprietors.—Task-work has certain advantages over work by the day, for the laborers are free to select their own time, and by more active exertions they can shorten their hours of labor. When the municipal council of a commune has arranged a basis upon which it can convert day's work into task-work, and this schedule has received the approval of the prefect, the mayor of the commune may decide, so far as the smaller rcads are concerned, whether work in his commune shall be done by one system or the other, as he may deem best. This decision is binding upon all the prestataires who have declared their intention of working out their taxes. The prefect of the department may in a similar manner decide as to the execution of work upon the main highways and roads of common interest to several communes.

When such task-work is to be done, the requisition states the class and amount of work and the date by which it must be completed. The character of work required is further indicted upon the ground by the inspector of .the canton, and it is carried out under his direction. The party assigned to a task is responsible for its proper execution; and upon the receipt of the measurement and certificate of the inspector that it is properly done and within the given time, the mayor accredits the farmer with his task. Work improperly done must be done over again, and within a time fixed by the mayor.

Contract Work.—The mayors, with the authority of the prefect for vicinal roads, and the prefect for the main highways and smaller roads common to several communes, may let by contract the construction and repair of these roads, But under the law of 1836, the proprietors, even when the work is converted into tasks, cannot be credited for taxes with work done under the control and for the

account of a contractor. Nevertheless, when work on any department road is let by contract, the conditions of the contract oblige the contractor to receive in return for services the day work or tasks of the proprietors according to a conversion tariff approved by the Council General of the department in the first case, and by the municipal council with the approval of the prefect in the second case.

In cases where the department supplies this labor in lieu of taxes from the laborer and cash paid to the contract or, the department by its agents makes the requisitions and superintends the execution exclusively; the contractors having nothing to do with the disposition of the men. But if the prestataires do not carry out their obligations, the contractors may call upon the mayor or the inspectors to compel the fulfilment of these obligations.

Cash Work.—In theory all work for which money is paid should be executed under a public contract. Nevertheless, with the authority of the prefect certain work may be let by private argreement under the following conditions:

(1) For work or supplies when the value does not exceed $600.

(2) For work when the conditions forbid the delay of a public letting.

(3) That which by its nature requires special skill and experience on the part of the contractor.

(4) That which cannot be let by contract after two several attempts to do so. Work may also, with the authority of the prefect, be economically carried out either directly under the control of the inspectors, or by way of indirect taxes, in cases of urgency or when other methods of execution have been recognized as impossible or less advantageous. Under these conditions the work should, if possible, be accomplished by the task system.

All projects must be approved by the prefect, and all specifications for work must contain the clause that the contracts are subject to the general conditions imposed upon contractors for vicinal roads as annexed to the general instructions issued on December 6, 1870.

The provisional or final acceptance of work performed upon main highways or roads common to several communes lies with the inspector of the arrondissement, assisted by the inspector of the canton, and made in the presence of the contractor. The accept-

ance of vicinal roads lies with the mayor in the presence of the inspector of the canton, two members of the municipal council, and the contractor. The contractor is always summoned on these occasions, but his absence is no obstacle to the action of the officials.

All difficulties arising from disagreement as to work performed on vicinal roads, or from damage caused by these works, and not arising from a material expropriation of lands, can be adjusted by the council of the prefecture, with appeal to the council of state.

Commissioners of Supervision.—In some departments, the prefects have thought it proper to delegate a portion of the care of inspection required by the many details of work on vicinal roads to a commission appointed by the prefect and made up from members of the General Council, the councils of the arrondissements, the mayors, and certain proprietors particularly interested in the good condition of the roads. Where a road passes through two arrondissements and is too long to be easily watched by one commissioner, it may be divided, and its several parts supervised by distinct commissioners. Each commission names its own president and secretary and fixes the day and place of meeting. When the prefect or sub-prefect attends a meeting, he is the president for the time being.

When the prefect thinks best, these commissioners may be consulted upon projects recommended by the inspectors for new works, and upon a basis of a division of expenses between the communes. They may also designate several of their number to take part in the acceptance of work done by contract. Within the first three months of the year, these commissioners send to the sub-prefects their observations upon the state of the roads and point out the localities most urgently needing repair. In this report they also name the workmen who have most faithfully performed their duty, as well as those who have been careless or slow in the performance of their work.

The Police of the Roads.—No one without previous authority can perform any act upon a road that in any way interferes with its function as a public way or interrupts travel. And it is specially forbidden to make any trenches or openings; to deposit stones, earth, or rubbish upon it; to take away any sand, gravel, or other material; to spread anything over the road; to divert water channels so as

to cause washing of the road; to interrupt in any way the flow of water in the ditches, even temporarily; to construct or repair any building, wall, etc., bordering upon the road; to open ditches, plant trees or hedges along said road, or to dig wells or cisterns nearer to the road than provided in the regulations. To perform any of these intended acts, authority must first be formally requested. For all vicinal roads this authority is granted by the mayor with the advice of the inspector; and in no case can the mayors give a verbal authorization. For main highways and other more important roads the authority comes from the prefect, upon the report of the inspectors, or from the subprefect under similar advice. Every authorization expressly reserves the rights of third parties, and stipulates that the roads must be restored to their normal good condition.

Ditches and Slopes.—In giving to the department commissioners or to the Council General the right to give to vicinal roads the necessary width, the law of 1871 accorded them the right to include all the land required for proper ditches and slopes. These ditches must be cleaned as often as necessary, and the expense of so doing is charged to the commune; the ditches being a legal part of the road, and protected against encroachment in the same manner as the road proper. If the authorities have not opened a ditch along the whole length of a road, as sometimes happens, the bordering proprietors may do so by first having the lines and levels given them by the proper parties; without this authority they are expressly forbidden to touch the ditches. The care of ditches opened for their own protection and convenience lies in the hands of the proprietors.

Rural Roads.—Outside of the vicinal roads properly so called, there are in all communes a certain number of minor roads or means of communication which, while of little importance, perhaps, must yet be carefully maintained, as they may lead to a public fountain, a watering-place for cattle, or to common pasturage. Such roads are termed rural roads in the law of 1839, but they are really public roads in the sense that their use is open to all, that they cannot be claimed as private property by the owners of adjoining soil, and that they are legally under the care of the public authorities and are maintained in the same manner as are other roads of the commune.

The method adopted is to map every road and every public path in the commune, and expose this plan for one month at the office of the mayor of the commune. Any objections made to the correctness of the plot or claims of private ownership of roads shown are submitted to the municipal council, which is to sift out those having a basis of fact. And this same official body renders an opinion upon the degree of utility of the roads shown, and the possibility of suppressing certain ones so that the soil may be sold for the benefit of the commune. The map with the report of the municipal council is then submitted to the prefect of the department, who examines it to see that no vicinal roads have been included under the head of "rural." The opposition to the official dedication of a certain road may be founded upon a claim of property, or upon the fact that it is not public. The property claim is decided in the courts of justice; the second case must be decided by the administrative power, that is, the prefect.

When a minor road of this kind is definitely classified as a "rural road" it is public property, and the administrative authority itself cannot restrain travel on it except in case of absolute necessity. If a commune wishes to enlarge such a road, it can do so only by an amicable agreement with the owner of the necessary land, unless the prefect officially classes it among the vicinal roads. If a rural road is suppressed, the soil can be sold for the benefit of the commune; but in such case the proprietors bordering on such a road can either demand that the use of it be continued to them, or that the commune provide some other passage or pay them an indemnity.

868. Street Cleansing.—Although circumstances legitimately determine the intervals at which streets shall be cleaned, nevertheless clean, well-swept streets not only add materially to the prosperous appearance of a town, but they also have a very marked influence upon the health and morals of its inhabitants; wet and muddy, badly-formed, ill-drained streets cause dampness in the subsoil of the dwelling-houses in the vicinity and a humidity of the atmosphere, both of which tend to produce a low standard of health in their neighborhood, irrespective of the wet surface through which pedestrians have to wade whenever they are obliged to cross such streets.

Dusty streets, too, are very injurious from the gritty silicate-loaded air arising from them. Such an atmosphere when inhaled is known to produce disease of the lungs, even when free from the dust arising from horse-droppings or other organic impurities.

869. The dirt-producing causes common to all roadways are:

(1) Detritus produced by the attrition of the paving material, horseshoes, wheel-tires, and shoe-leather. This cause cannot be eliminated.

(2) The horse-droppings, which add an offensive element to the body of street dirt, are, if collected at once, valuable as manure. This is done by the street orderly boys in London. If properly cared for, it would undoubtedly afford an income greater than the cost of collecting it.

(3) Dirt forced up through the joints of block pavements. Under modern specifications the joints of block pavements are intended to be closed with a water-proof material. This of course would give full protection against this source of dirt, but in the majority of block pavements it is doubtful if this requirement is ever faithfully performed. A few months generally suffices to dislodge the imperfect filling, and the material of the substratum quickly shows itself on the surface of the pavement.

(4) House and shop refuse carelessly swept into the streets is an ever-present source of street dirt. London imposes and enforces a fine of not less than \$25 and not exceeding \$200 upon any person sweeping or throwing any refuse, dirt, ashes, dust, decayed fruit, or offensive matters of any kind upon the foot or carriage ways. Also any person refusing to have the dust or ashes removed by the scavengers or obstructing them in the performance of their duties is liable to a penalty not exceeding \$25. Again, the method of removing house-refuse is a prolific source of street dirt. The receptacles containing it are brought out and are placed on the edge of the curb long before the cart makes its appearance or can be reasonably expected to do so.

870. The result of these receptacles, filled with heterogeneous collections of house-refuse, being left unprotected in the public streets is that their contents are quickly strewn about the surface of the street, by their being upset accidentally or purposely; and the appearance of the street, which has probably been carefully

swept and garnished during the night or early in the morning, quickly assumes, especially in a high wind, a very offensive character, and probably has to be re-swept and cleansed before the ordinary traffic of the day commences.

871. With good pavements the amount of refuse to be removed is reduced to a minimum. With pavements the wear of which is practically nothing, the dirt consists principally of manure, which has a ready sale. The reduction in the amount of unsalable refuse is an object to be sought for; its collection and disposal is an expensive item. This reduction can only be effected by the adoption of impermeable pavements.

In Berlin and Liverpool the average quantity of refuse collected by sweeping has been continuously decreasing in spite of increased traffic and area, this reduction being due to good pavements.

872. Composition of Street Dust.—The following analysis of street dust is given by Mr. H. G. Hanks, State Mineralogist of California. The samples, examined under the microscope, contained vegetable fibre, principally horse-manure and the decaying débris of Oregon pine and redwood planking, bits of coke and coal, glass, horse-hair, quartz sand, some blue particles the nature of which could not be determined, and a dark-colored, finely-divided, half-dried mud which was pleasant neither to the sense of sight or smell. A portion mixed with distilled water and placed in a bottle swarmed with life in forty-eight hours.

Professor Tyndall has also shown that dusty air is alive with the germs of the bacteria of putrefaction, whilst the pure fresh air which he gathered on a mountain peak in the Alps is devoid of such germs, and is absolutely powerless to produce any organisms. Persons living in streets that are improperly swept or watered are unable to open doors or windows with impunity by reason of the dust.

Dr. Letherby, in 1867, analyzed dry mud from the streets of the city of London—dried by exposure for many hours to a temperature of from 266 to 300 degrees Fahr. At the same time he analyzed, for comparison, well-dried, fresh horse-dung and common farm-yard dung. The results of the analyses of the mud from stone pavements are given in Table LXXXV.

TABLE LXXXV.

COMPOSITION OF MUD FROM STONE-PAVED STREETS, HORSE-DUNG AND FARM-YARD DUNG.

(Dried at 300 degrees Fahr.)

Constituents.	Fresh Horse-dung. Per cent.	Farm-yard Dung. Per cent.	Mud from Stone-paved Streets.		
			Maximum organic (dry weather). Per cent.	Minimum organic (wet weather). Per cent.	Average. Per cent.
Organic............	82.7	69.9	58.2	20.5	47.2
Mineral............	17.3	30.1	41.8	79.5	52.8
	100.0	100.0	100.0	100.0	100.0

The higher proportion of mineral matter in wet weather proves that in such weather the abrasion of stone and iron is greatest. Dr. Letherby estimated that the average proportions of stone, iron, and dung in the muds were:

Horse-dung..	57 per cent
Abraded stone..	30 "
Abraded iron..	13 "
	100 per cent

The mud was so finely comminuted that it floated freely away in a stream of water.

In the mud of wood pavements, the proportion of organic matter in the dried mud was larger than in the mud of stone pavements. It amounted to about 60 per cent.

The amount of moisture in the street mud varied according to the state of the weather.

Stone Pavements.	Moisture.
In the driest weather....................	rarely less than 35 per cent
In ordinary weather....................	" " " 48½ "
In wet weather....................	" " " 70 to 90 "

873. The detritus of the material of a granite pavement constitutes but a very small proportion of the total quantity of mud-

forming dust. Colonel Haywood exemplified this proportion in an interesting manner, taking the instance of the granite pavement of London bridge,—3-inch Aberdeen granite sets,—which was removed in 1851, after having been down nine years. The average loss of granite over an area of 3950 square yards, he estimated, was equal to 2 inches of vertical wear. The total volume of granite worn away was therefore about 219½ cubic yards, assuming that the surface was a continuous mass of granite, though there was of course a considerable superficial area of joints. Assuming that the granite worn off was reduced to the state of fine powder, it was increased in bulk probably one half, and its volume had been (219½ × 1½ =)329¼ cubic yards. Adding 5% for the loss upon stones removed and replaced from time to time, the total quantity worn off and reduced to powder and carried away, mixed with the dust of the street and mud, would only have amounted to 345.7 cubic yards for nine years, equivalent to a wear of .105 cubic yard —about a tenth of a cubic yard—per day. Whereas the quantity of dust removed daily in dry calm weather was from 3 to 3½ cubic yards—over thirty times as much as the granite detritus. So much for horse-droppings and shoe-leather, which must have constituted twenty-nine thirtieths of the total accumulation, independent of the contributions of house-refuse, in the inhabited streets. Table No. LXXXVI shows the number of cubic yards of street-refuse collected in a few cities.

TABLE LXXXVI.

AMOUNT OF REFUSE COLLECTED FROM CITY STREETS.

City.	Street Mileage.	Refuse removed. Cubic yards.
Baltimore	780	180,000
Boston	73	70,499
Brooklyn	365	259,398
Buffalo	225	100,000
Chicago	660	150,000
New York	341	535,709
Philadelphia	700	266,831
Washington	125	127,623
St. Louis	440	200,000

874. The relative amount of dirt produced by the different pavements, if swept daily, appears to be about as follows:

Pavement.	Cubic Yards per 1000 Yards of Surface.
Asphalt	.007 to .04
Wood (impervious joints)	.04 " .07
" (open joints)	.07 " .20
Granite (impervious joints)	.015 " .024
" (open joints)	.07 " .25
Macadam	.10 " .35

These figures are only approximations and will vary with the amount of traffic, state of the weather, and character of the pavement of intersecting streets: if these are productive of dirt, a large quantity will be dragged by the vehicles on to the good pavement, which is thus debited with a large quantity of material which does not rightfully belong to it.

The care exercised in the removal of the ashes and garbage by the occupiers of the buildings on the street will also influence the amount of dirt to be removed.

875. Methods employed for Cleansing.

(1) By hand during the day.

(2) By hand during the night.

(3) By hand and machinery during the night, supplemented by a street orderly or patrol system during the day.

Of the above methods each locality will have to decide upon the one which is best suited to its requirements. For large cities the third method is the most suitable.

876. Systems of Executing the Work.

(1) By contract; the contractor furnishing all the tools and labor.

(2) By contract for the labor only, the city furnishing the tools and machinery.

(3) By contract for the horses and removal and disposal of the refuse, the city furnishing the labor and machinery.

(4) By the city, with its own staff and machinery.

Cleansing by contract has generally proved unsatisfactory, from the difficulty of obtaining a proper observance of the terms of the

contract by the contractor and his employés, and it has been found that the work can be more carefully and systematically carried out by the civic authority with its own officers and staff. It is, perhaps, true that the work may be done under the contract system at less actual cost to the taxpayers, but all public work should be done in the best manner possible irrespective of cost, thoroughly, but without extravagance; and the result of such work, especially where it affects the cleanliness and the appearance of a town, soon fully repays any moderate extra cost that may thus have been incurred, irrespective of the enormous benefit that is conferred upon any community by the reduction of disease and the death rate by a proper attention to such necessary sanitary work.

877. Cost of Cleaning.—The average cost of cleaning the different pavements appears to be as follows:

Asphalt	.003	cent per square yard per cleaning
Stone block	.005	" " " " " "
Wood	.007	" " " " " "
Brick	.0034	" " " " " "
Broken stone	.0106	" " " " " "

The average cost of supervision varies from .011 cent to 34 cents per mile.

The cost per mile of street cleansed varies as follows:

Omaha, Neb.	$16.00
St. Louis, Mo	17.00
Boston, Mass	20.00
San Francisco, Cal	20.75
Brooklyn, N. Y	22.75
Cleveland, Ohio	22.90 to 70.00

The amount annually expended per head of population in street cleaning is shown in the following table. It varies from 5 cents in Buffalo and 8 cents in Chicago to 71 cents in New York and 92 cents in Cincinnati.

878. The method of cleaning employed in Berlin, which is said to be the cleanest city in Europe, is as follows:

The men are city employés.

The sweeping-machines are city property, but the horses are hired by contract.

TABLE LXXXVII.

AVERAGE ANNUAL COST PER HEAD OF POPULATION FOR STREET MAINTENANCE.

Cities.	Average Cost per Head of Population.	
	Construction and Repairs of Streets.	Street Cleaning.
Baltimore, Md	$0.28	$0.25
Boston, Mass	1.84	0.30
Brooklyn, N. Y	0.49	0.20
Cambridge, Mass	0.64	0.36
Camden, N. J	0.38	0.19
Canton, Ohio	1.22	...
Chicago, Ill	3.18	0.08
Cincinnati, Ohio	2.88	0.62
Cleveland, Ohio	1.34	0.19
Dallas, Texas	0.47	....
Davenport, Iowa	1.12	0.19
Detroit, Mich	1.63	0.16
Duluth, Minn	15.00	0.15
Elmira, N. Y	0.40	0.07
Evansville, Ind	0.66	0.15
Fall River, Mass	0.89	....
Hartford, Conn	0.88	0.11
Hoboken, N. J	0.46	0.05
Lacrosse, Wis	0.81	....
Lawrence, Mass	0.74	0.07
Lowell, Mass	1.27	....
Lynn, Mass	0.72	0.18
Minneapolis, Minn	1.21	....
Nashville, Tenn	1.71	....
Newark, N. J	0.11	0.16
New Haven, Conn	1.68	0.06
New Orleans, La	0.14	0.10
Newport, Ky	0.60	0.16
New York, N. Y	0.68	0.71
Omaha, Neb	4.15	0.16
Philadelphia, Pa	0.61	0.27
Rochester, N. Y	1.06	0.15
Rockford, Ill	0.51	0.08
St. Louis, Mo	1.85	0.28
St. Paul, Minn	5.69	0.28
San Francisco, Cal	3.21	0.30
Sioux City, Iowa	30.05	0.16
Springfield, Mass	....	0.28
Taunton, Mass	1.41	....
Toledo, Ohio	4.03	0.10
Trenton, N. J	0.17	0.03
Washington, D. C	2.50	0.81
Worcester, Mass	1.65	0.06

The removal of sweepings is also done by contract; the contractors for this work being obliged to maintain suitable dumping-places, in return for which they receive for their free use the street sweepings. These sweepings are of some value, the contractors often realizing over $20,000 per annum from them.

The contractors are bound under all circumstances to supply enough wagons to remove each day all street waste. The number of wagons required varies with the weather. In dry weather often hardly half so many wagons are needed as in wet weather. They are required to remove the rubbish as soon as it is swept up, and only in cases of bad weather are the sweepings allowed to stand more than one hour before being carted away. If these regulations are broken, the contractors forfeit a certain amount to the city.

The streets are cleaned during the night.

The number of men employed by the city is about 600, and the number of sweeping-machines in use in 1889 was 42.

The area cleaned in 1889 was 3,361,312 square yards.

The average daily amount cleaned by each man was 5716 square yards.

The area swept by a machine ranges from 6545 square yards on bad pavements to 10,315 square yards per hour on asphalt pavement.

The total expenses of the street-cleaning department in 1888 and 1889 were $481,493.48, made up of the following items:

Wages	$193,261.44
Uniforms	2,769.12
Tools, materials, etc	44,819.76
Carting away	182,487.12
Sprinkling	53,110.56
Depots for supplies	1,221.12
Public closets	1,279.44
Miscellaneous	2,544.48
	$481,493.04

Of this sum the street-car companies paid for cleaning and sprinkling the parts of the street occupied by their tracks the sum of $24,135.58.

The quantity of refuse removed from the streets was as follows: In 1882–83, 95,493 wagon-loads; in 1888–89, 97,969 wagon-loads.

The number of loads, therefore, varied very little in spite of the considerable increase of area cleaned. In fact in the year 1888–89 the number was about 16,000 less than in 1878, when it amounted to 113,994 wagon-loads. This was due to the constant increase of good, impervious pavements.

The wages of the laborers employed in the street-cleaning department vary between 36 and 83 cents per day, in addition to which they receive uniforms free. The salaries of inspectors range from $357 to $636 per year; they also receive their uniforms free.

New employés after $1\frac{1}{2}$ years service are advanced to a higher grade.

The men are paid for Sundays and holidays, and in case of sickness receive half-pay. Old workmen are pensioned after 10 to 15 years' service at $100 per year, and for 30 years or more $150. With relative allowance between, the number of pensioners in 1889 was 11. Assistance is also rendered to sick employés. In 1889 about $100 was expended for this purpose.

879. In Paris street sweeping is performed by 2200 men, 950 women, and 30 boys. They begin work at 3 A.M. in the summer and at 4 A.M. in the winter and continue without interruption till 11, when the work for women ceases; the men continue for 10 hours and are paid by the day from 65 to 74 cents. The women are paid 6 cents per hour and cannot earn more than 45 cents a day. All are obliged to provide their own brooms. The plant consists of upwards of 200 mechanical sweepers.

The amount of refuse removed daily averages 2300 cubic yards and requires the daily use of 520 carts and 980 horses. The refuse is disposed of by public tender to contractors for a term of four years.

880. The cleansing of the city of London is carried out under the department of the commissioners of sewers. The force employed consists of about 500 men, women, and children. The work begins at 8 P.M. and is concluded at 9 A.M. The street orderly boys begin work at 7.30 A.M. They number about 150, and their duty is to remove every particle of dirt, especially horse-droppings, in the area assigned to them before it has been ground by the wheels. Bins at the street curb receive the gatherings. Not only the more important streets, but minor ones, courts and alleys are looked after by the orderly boys. These boys are lodged and

fed by the city, a certain deduction for the purpose being made from their wages. As they reach manhood they are promoted to other positions, and when they attain old age, after faithful service, they are pensioned.

The courts and alleys inhabited by the poorer classes are cleaned daily, and from May to October are washed with jet and hose usually twice a week.

881. Baltimore, Md.—Population, 443,547. Street mileage cleaned (1891), 780. Total expenses of street-cleaning department, $283,070.54.

Distribution of expenses:

Collecting garbage	$139,062.16
Cleaning streets and removing dirt	118,423.00
Dumps	4,689.40
Tools	2,404.50
Superintendence	9,991.48
Removing garbage from city (contract)	8,500.00
	$283,070.54

The equipment consists of 150 garbage carts, 61 street-dirt carts, 136 scrapers and sweepers. Work executed by city employés. The wages paid range from $10 to $18 per week. The sale of street dirt and refuse realized $912.76.

882. Boston.—Henry B. Wood, Executive Engineer of the street commissioners of the city of Boston, in a recent communication to the daily press says: That modern hygiene calls for constant attention to the immediate removal of all kinds of street refuse from public highways and places before fermentation takes place, or disease-laden gases or dust, particles emanating therefrom can be disseminated. A mere occasional attempt to clear up what street litter we cannot climb over is not sufficient; indeed, the pavement must now be swept so clean that it is passable at any point for pedestrians. He continues:

"The number of miles of streets cleaned is 7273.24, at an average cost of less than $20 per mile, and the number of loads of street dirt removed is 77,000. The entire force of men employed has been about 300. Some streets have been swept every day, in sweeping weather; some three times a week. Each day's work has been so

assigned that the computed area covered per week has been figured up to about 590,000 square yards to a district.

"For a paved district of said area a good working gang is composed of one foreman, one sub-foreman, two sweeping-machine drivers, two water-cart drivers, sixteen sweepers, six teamsters, six helpers, and one dump inspector, allowing a trifle over one sweeper to a mile of gutter-stroke. Such a force costs about $23,000 for a full year. Eighty-one per cent of the streets are either gravel or macadam, and the cost of cleaning averages about $65 per mile for each cleaning.

"The introduction of the push-cart patrol system as an important adjunct to the regular street-sweeping force has found approval in the tidy appearance of the business thoroughfares. It is found that, even after a street has been once thoroughly swept, in less than two hours' time the sweeping of the sidewalks and the throwing away of waste material into the street will so disfigure its surface that it appears as though the street-cleaning force had neglected it in its daily rounds. To obviate this difficulty the push-cart patrol comes in, collecting and removing this refuse matter continually throughout the day."

883. Brooklyn, N. Y.—Population, 806,343. Street mileage cleaned, 380. Expenses of street-cleaning department, $239,875; supervision, $36,000. Work done by contract. Cost per mile, $22.75; cost per capita, 30 cents.

884. Cleveland, Ohio.—Population, 261,456. Street mileage cleaned, 680. Expenses of cleaning department (1891), $116,-099.51. Work done by contract. Dry-weather cleaning, $22.90 per mile; spring cleaning and scraping, $45.80 per mile; wet-weather cleaning, $70 per mile. Cost per capita, 42 cents.

885. Detroit Mich.—The streets are cleaned when and as often as necessary. The work is done by day's labor, with the aid of sweeping-machines. This work is principally performed by aged persons who cannot do a full day's labor and cannot obtain work elsewhere. The purpose in employing labor of this character is to preserve the independence of the men and keep them from becoming paupers. Eight hours constitutes a day's work, and $1.50 per day is paid. The hours and per diem allowance are fixed by the common council.

886. In New York the street cleaning is executed by the

municipal authority under the direction of a special bureau, part of the labor being furnished by men in its employ and part by contract; the carts are also furnished by contract.

The total number of men employed ranges from 1500 to 2000, and the number of carts is between 300 and 400. The amount of sweeping collected per annum is about 550,000 cubic yards. The number of sweeping-machines employed is about 60. The number of miles of street swept each day is about 60, tri-weekly about 200, and bi-weekly about 70. The refuse is deposited at sea, and it costs 18 cents per cubic yard to place it on the scows.

The cost of cleaning the above street mileage, equal to an area of about 314,179,328 square yards, is about $1,279,647 per annum.

887. Philadelphia, Pa.—Population, 1,046,252. Street mileage cleaned, 756. Work done by contract. Expense of street-cleaning department, $552,000; supervision, $11,920. Ashes are removed weekly, garbage daily. Amount of refuse removed in 1891: garbage, 84,065 loads; street dirt, 290,680 loads; ashes, 573,999 loads; dead animals, 14,795. Number of men employed, 400; number of machines, 17. The average number of miles cleaned per man was 118.

888. St. Louis, Mo.—Streets paved with granite and wood swept by contract at 50 cents per 10,000 square feet per sweep. Asphalt pavements, 39 cents per 10,000 square feet per sweep. The macadam and Telford cleaned by hand labor, under the supervision of the street department.

889. St. Paul, Minn.—Population, 133,156. Street mileage cleaned, 349.

Total cost of cleaning by city force in 1891:

	Labor.	Materials.
Unpaved streets	$35,470.11	$119.11
Paved streets	20,296.27	1,121.32
Total	$55,766.38	$1,240.43

Cost of cleaning 30,000 square yards of asphalt pavement by hand under contract, $49.75 per week.

Paved streets are scraped with hoes in the spring at a cost of about $35 per mile, and are afterwards kept clean with sweeping-machines at a cost of about $9 per mile.

890. Washington, D. C.—The cleaning of the streets is at present performed by contract, at the rate of 33 cents per 1000 square yards for each sweeping. The improved alleys are cleaned under another contract at the same rate. The remainder of the work is done by hired labor, supplemented to some extent by men from the District workhouse. The extent of streets swept by the contractor is 3,102,026 square yards, equal to 126.37 miles.

The remaining streets within the city, which are cleaned by hired labor and the chain-gangs, are as follows:

Pavement.	Square yards.	Length, miles.
Macadam	270,320	8.0
Gravel	591,418	29.4
Total	861,738	37.4
Unimproved	1,272,695	71.9

The contractor uses ten four-horse sweepers, five of the Wright and five of the Filbert pattern. The sweeping is done by night, except when the contrary is specifically authorized.

The amount of material removed from the streets averages 1¼ cubic yards per sweeping to every 3000 square yards of area swept. Before sweeping the route is sprinkled by the contractor at his own expense. The average force employed by the contractor, besides the 10 large sweepers, consists of 4 sprinkling-carts, from 40 to 50 broom, hoe, and shovel men, and between 30 and 35 carts. The maximum force here named will clean 900,000 square yards of pavement in 12 hours. The total cost of the cleaning is divided between the government and the city, the cost per capita being about 21 cents per year.

891. Street Orderly or Patrol System.—This system comprises a staff of men or boys usually the latter, equipped with a bag or scoop and a brush. Each boy is assigned to a definite area, from which he removes all horse-droppings and refuse as it falls and before it has time to be ground up by the wheels. The pans are of sheet-iron formed as shown in Fig. 236. The bags are of canvas and are shaped like an old-fashioned carpet-bag; one of the lips is provided with a

metal edge over which the refuse is swept. The brush is generally made of a bundle of birch twigs.

The refuse so collected is disposed of in different ways.

In London cast-iron boxes are fixed at the curb into which the boys empty the scoops when filled; the receptacles are in turn emptied by shovels into carts at stated intervals.

The bag is claimed to be better than the scoop; it holds more than the scoop, and therefore requires less running to the receptacles to be emptied, and it covers up the refuse; but the emptying process is always troublesome and can hardly be conducted without considerable dirt being scattered in emptying.

In Paris the refuse is collected in a similar manner, but instead of sidewalk receptacles they have a light wrought-iron vehicle proportioned to carry four full bags, two inside and two suspended from hooks on the outside. This system fills the bags at once, allows them to be stored without offence or dirt anywhere, and the final removal is expeditious and cleanly. Fig. 237 shows the hand-cart used by the street patrol in New York and several American cities.

892. Street cleansing is effected either by hand sweeping and scraping or by mechanical sweepers. As to which is the most economical, much depends upon the value of labor, and also upon the condition of the roads to be dealt with. On pavements covered with ruts and depressions machine brooms are not effective, but in point of time and as a general rule the value of a horse rotary-brush sweeping-machine is undoubted; the only time at which such a machine fails to do effective work is on the occasions when the mud to be removed (owing to a peculiar condition of the atmosphere) has attained a semi-solidity, and is of a stiff and sticky consistency, when it either adheres to and clogs the brushes of the machine, or is flattened by them onto the road instead of being removed. In such a condition of the street the scraping-machine must be employed, but care must be exercised in its use, as there is always danger of injuring the pavement.

893. Cost of Street Sweeping.—City Engineer Rundlett has kept a careful account of sweeping the paved streets of St. Paul, by hand and by machines. The average cost by hand in May was $25.00; June, $20.18; July, $18.57. Total average per mile by hand, $20.00; by machine, $9.24.

In cleaning the streets of St. Louis the bids for cleaning asphalt pavements are 25 per cent below those based on granite block.

In Washington the street cleaning costs from 29 to 35 cents a thousand yards, cleaned once.

894. The amount of surface which one man can sweep per hour depends upon the condition of the pavement, dry, wet, or muddy. The following figures are approximate:

Asphalt, dry	1200	square yards per hour.
" wet and muddy	1000	" " " "
Granite block, dry	1000	" " " "
" " wet and muddy	750	" " " "
Macadam, dry	700	" " " "
" wet and muddy	350	" " " "

895. The amount of surface cleaned by a mechanical sweeper will depend upon the width of the machine broom, the power of the horses, gradient, and condition of the surface. The wider the stroke of the broom the less will be the cost of sweeping. As the width of stroke differs in different machines, the area swept by each in a given time will vary with that width.

The average speed of the mechanical sweepers is one and a half miles per hour.

896. The cost of operating a machine sweeper is about 50 cents per hour. With a machine having a stroke of 5½ feet it will require six strokes of the machine to sweep a 30-foot roadway; therefore, to clean one mile of roadway 30 feet wide, such a machine must travel six miles, and will require about four hours and, at 50 cents an hour, cost $2.00. With a machine having a stroke of 8 feet, but four miles' travel of the machine will be required.

897. Brooms.—The hand brooms used are made of steel wire, rattan, bass and birch. As the strength and durability of these brooms is of some importance as affecting the ultimate cost of street sweeping, care should be exercised in their selection.

Steel wire lasts longer than any other, but is only suitable for block pavements. Bass and birch are weak and speedily wear out. Rattan is most suitable for asphalt and Macadam pavements. Rubber squilgees or mops are most efficient for cleansing asphalt pavements.

898. Carts and Wagons.—The carts and wagons employed in the removal of street dirt should be provided with covers. The employment of wooden carts for this work is not economical; the rough usage which they receive renders their life but a short one, and they are constantly requiring repair. Iron or steel should be substituted. Such carts are to be purchased in the market and have many points to recommend them.

899. The methods employed for the final disposing of the street refuse are many and varied. In the seaboard cities and those situated on rivers it is generally placed on barges, carried to sea or other deep water and deposited. In others it is used for filling in low lands (a practice which cannot be too strongly condemned). In a few localities it is destroyed by fire. This is the superior method and quite successful, and is gaining in favor in situations where difficulties are encountered in disposing of the refuse, the only objection raised against it being the offensive odor. This odor is not so bad as people imagine; it approximates that of burning leather and can be entirely avoided by suitable devices and chimneys of sufficient height. As a rule, people are prejudiced against crematories being located near their residences.

The cost of a plant for a town having a population of 100,000 would be about $100,000. The cost of cremating the refuse ranges from 20 to 40 cents per ton, depending upon the amount of combustible the refuse contains.

900. Removal of Snow.—An important feature of maintenance is that involved in the removal of snow. Good management implies that it shall be speedily removed and not left to interrupt travel.

901. In American cities no provision is made beforehand for the extra assistance required for its removal, and all that can be done is to collect as many teams and men as possible at the moment; the result is that much valuable time is wasted in this operation. In European cities, this extra labor is engaged in advance. In Paris a contract is made each year with the general omnibus company to supply carts and horses at any time needed. In London also, contingent contracts provide for any additional number of teams required at a moment's notice.

902. The organization and arrangements for the removal of snow in the cities of Milan and Turin, Italy, are the most complete

of any city, and a description of their methods may be interesting.

The system adopted in Milan is as follows: The city is divided into districts of varying extent according to their importance; each district is allotted to a contractor, who has to find the carts, horses, and laborers, while the city furnishes the necessary implements, spades, shovels, brooms, scrapers, barrows, etc., with proper stipulations as to their care. The contracts are made annually, and generally the same persons are anxious to secure them. The form of the contract is rigid, and the contractors, who are drawn from the trades most affected by winter—paviors, bricklayers, masons, quarrymen, etc.,—are held to a rigid responsibility. Payment is only made for work which is well done; slovenly and careless execution goes for nothing. The supervision of each district is under an engineer aided by assistants and the police.

Payment is made per inch depth of snow fallen. The average depth of the snowfall in each district is determined from the depth of the snow caught on a number of stone posts fixed in open spaces and clear of shelter from buildings. Each post is capped with a flat slab set horizontally. The depth of the snow on these slabs is measured by the engineer of the district in presence of two of the contractors of his section.

The average cost of removing the snow per inch of depth per square yard is .006 cent. Ordinarily the removal of the snow from the more active thoroughfares is finished within ten hours of the cessation of the storm, and from the rest within 24 hours, exclusive of night.

The snow is dumped into the navigable canals and water-courses intersecting the city, and latterly into the new sewers in the central portions of the city, which are promptly flushed whenever it snows.

The number of men engaged in the removal of snow in addition to the regular street-cleaning force, ranges from 2000 to 3000, according to the severity of the storm. The implements are housed in different storehouses throughout the city. The whole expense of removing and disposing of the snow during the remarkable winter of 1874–75, when more than 40 inches of snow fell, was about $44,000. In the case of each storm the work of removal was done within 24 hours.

903. In Turin much the same method is practised, work being

paid for by the exact measure of snow fallen. The street-car companies are obliged to bear their share of the expense, paying for a width of 9 feet 10 inches for single and 18 feet 8 inches for double tracks.

904. Many schemes for the disposal of snow have been experimented with, such as dumping it into the sewers, melting it by the application of steam, hot air, etc., as also with salt; but the only successful scheme so far is by cartage, depositing it in adjacent streams, or where this is objectionable, as in the case of navigable rivers, it may be heaped up in vacant lots or in the squares and parks, provided no damage is done to the grass or paths.

905. Dumping the snow down the manholes into the sewers has been tried in London and other cities, but has generally failed through the snow consolidating. An experiment with this method in the city of Cologne gave the following results. A number of shafts were opened into the crown of the main sewer that empties into the Rhine, each shaft being from 2 to 5 feet square. At one of these places the sewer was of oval section, 6 feet $\times$ 4 feet, and the fall was 1 : 600. It was possible to dump the snow directly from the carts, each of which held about two cubic yards, into the sewer without stopping the flow there. At another place where the sewer was 4 feet $\times$ 2.3 feet and the same fall prevailed, this process was not possible although a strong stream of water was thrown on the mass from the water service-pipes. The large mass suddenly thrown into the sewer acted as a dam and had to be removed. But at this same shaft when the same amount of snow was regularly thrown into it by four laborers no stoppages occurred. A few hundred feet below the place all the snow was found to be melted. Several hundred loads of snow were removed through these two shafts alone in a few hours.

The cost of melting snow by the application of hot air or steam far exceeds that of shovelling and carting away.

906. In order to grapple with this question of the removal of snow when no provision has been made beforehand, the following suggestions may be of use:

"It is useless to attempt to cart it away while falling, but try to make clear crossings for the foot-passengers and to keep the traffic open. If there should be a high wind at the time, and the snow drifts in consequence, cut through the drifts so as to allow

the vehicular traffic to continue. Directly the snow ceases to fall put on all available hands to clear the channel-gutters and street-gratings, in preparation for a sudden thaw, when, if these precautions were not taken, serious flooding and great damage to property might ensue; for the same reason cart away all the snow you can at the bottom of the gradients and in the valleys, and also from very narrow streets and passages, etc. In the wider streets use the snow-plough, or with gangs of men (in the snow season there is generally plenty of labor obtainable) shovel the snow into a long narrow heap on each side of the street, taking care to leave the channel gutters and gratings quite clear, and a sufficient space between the heaps for at least two lines of traffic. Passages must also be cut at frequent intervals through the heaps, in order to allow foot-passengers to cross the street, and also to let the water reach the channel-gutters as soon as the snow begins to melt."

907. With regard to the removal of snow from the footpaths, it is highly desirable that this should be effected by the occupiers of the premises adjacent to the street, as otherwise it adds immensely to the work of the local authority. The following interesting remarks by the superintendent of the scavenging department of Liverpool will be no doubt read with great interest:

"The only way to compass the removal of snow from the footwalks of the principal thoroughfares within a comparatively short time is by sprinkling them with salt such as is commonly used for agricultural purposes. It is certain that, unaided by the salt, a sufficient number of men cannot be procured for the emergency of clearing snow from the footways of the most important thoroughfares. It has been stated by medical authorities that the application of salt to snow is detrimental to the health of people who have to walk through the 'slush' produced by the mixture, and that the excessive cooling of the air surrounding the places where the application has been made is injurious to delicate persons. It therefore seems that the application of salt to snow should not be undertaken during the daytime, but should be commenced not before 11 P.M., nor continued after 6 A.M., and that only such an area of footwalks should be so treated on any one night as the available staff of men can clear by an early hour the following morning.*

* In New York and other American cities the use of salt for the speedy removal of snow is prohibited by ordinance, except on the switches of street railway tracks.—A. T. B.

"To sweep snow from the footwalks whilst the fall of snow continues, and especially during business hours, appears to be wasteful and futile, and to apply salt during the same periods may be held to be injurious to health.

"That the snow of an ordinary fall can be removed from the footwalks by an application of salt an hour or so before they are scraped is an ascertained fact, except at least when a moderately severe frost has preceded, accompanied, or followed the snowfall, or when the snow has drifted into extensive accumulations. Were it not for the danger to health by excessive cooling of the air, and for the expense attending the operation, all the impervious pavements could be cleared of snow (unless the fall was a heavy one) in a comparatively short time by a liberal application of salt and the employment of the horse sweeping-machines as soon as the snow has become sufficiently softened to admit of their use.

908. Weight of Snow.—Experiments made show that a cubic yard of fresh-fallen snow may weigh as much as 814 pounds or as little as 71, or a range of from 2.63 pounds to 30.14 pounds per cubic foot.

"Snow readily compresses under traffic, and when removed in carts and dumped elsewhere it may be assumed that on an average four cubic yards of snow measured as it has fallen is equal to one cubic yard when placed on the apparatus." This computation, however, does not make any allowance for the snow thrown from off the roofs, etc., and it of course greatly consolidates whilst travelling in the cart.

909. The removal of light falls of snow from country roads may be effected by the ordinary snow-plough forming it into a long narrow heap on each side, but taking care to leave the gutters unobstructed. Heavy drifts must be cut through with the shovel.

In some localities it may not be desirable to remove the snow, sleighs being used in place of wagons. In such cases care must be taken when a thaw sets in to have ditches and water-courses clear.

910. Street Washing.—Cleansing the pavements by washing them with a stream of water from the fire-hydrants is practised in both Paris and London. In the former city it forms part of the daily routine, but in the latter it is only used periodically, and more especially in the courts and alleys. Disinfectants are also used in Paris in this connection. During 1890 this method was experi-

mented with in New York. The results were not satisfactory; the muddy water collected in puddles in the hollows of the pavement, and the amount of mud and silt carried into the sewers threatened to soon choke them up.

This method is specially applicable to impervious pavements, such as asphalt and stone blocks and brick with water-proof joints. Wood pavements when they become covered with sticky mud are more easily cleansed by washing. In washing asphalt the sludge formed should be removed by the use of rubber squilgees; their use will also hasten the drying of the surface.

911. Street Sprinkling.—Streets are sprinkled with water for the purpose of laying the dust and cooling the air.

Two methods of applying the water are practised: (1) by hose attached to the fire-hydrants, and (2) by specially constructed carts.

The carts are preferable to the hose method; with the latter there is less regular distribution of the water, and in some localities there may be pressure enough to cause injury to the pavements. Again, the hydrants are generally located so far apart that long lengths of hose are required, and the constant rubbing soon wears them out. To obviate this metal pipe is employed in Paris; the pipes are usually in lengths of 6½ feet, mounted on two-wheeled trucks, and connected by flexible joints.

Carts cause less interruption to traffic, require less time and fewer men; moreover, when there is a scarcity of water they may be filled from wells or rivers.

912. Systems.—Three systems are practised for carrying out the work of sprinkling: (1) by the municipality, with its own equipment and men; (2) by contract, the contractor furnishing the labor and equipment; (3) by contract for the labor, the city furnishing the carts. The first system is generally the most satisfactory.

913. Quantity of Water required.—The quantity of water required will vary greatly, depending upon the character of the pavement and the temperature. The average number of gallons used in the United States per 100 square yards is 250; in Paris about 120 gallons per square yard; in London about 150 gallons.

914. Frequency of Sprinkling.—The frequency of sprinkling will depend upon local circumstances. In Berlin all the streets are sprinkled twice a day from April 1st to October 1st, and the principal thoroughfares and squares are sprinkled three and four

times per day in this period. For this work the contractor receives on an average $1.68 per day for each wagon. About 150 sprinkling-carts are used, each holding about 950 gallons. The street-car companies share the expense of sprinkling the streets occupied by their tracks.

In American cities the frequency of sprinkling the streets varies with the locality and the seasons of the year. The general practice appears to be about as follows:

Paved streets are sprinkled twice a day during the months of March, April, and November, three times a day during May and October, and four times a day during June, July, August, and September.

Unpaved, macadamized, and gravelled, streets are sprinkled twice a day during the months of March, April, May, October, and November, and three times a day during June, July, August, and September.

It is not usual to sprinkle the streets on Sunday, but in some few localities boulevards and driveways used on that day are sprinkled once or twice.

915. Cost of Sprinkling.—The cost of sprinkling is variable, depending upon the time occupied in travelling to and from the points where the water is obtained and where it is used. The range appears to be from 4 mills to 7 cents per 1000 square yards sprinkled.

916. Sea-water and deliquescent salts (as the chloride of calcium) have been used for street sprinkling. The surface is kept moist, but at the expense of the moisture in the air, and it is said that horses, hoofs are injured by the chemicals.

CHAPTER XX.

TREES.

917. Opinions differ as to the desirability of trees on roads and streets. Some claim that they do more harm than good; that they impede the circulation of the air, and that, as far the shade they afford, people who do not like sunshine have only to keep on the shady side of the way; that they deprive the road-surface of the drying action of the sun and air, and that in wet weather the constant dropping of water from their branches keeps the road in a muddy state. Others claim that trees, especially in streets, temper the heat and serve as a protection against dust, that the evaporation from their leaves tends to keep the surrounding air cool and moist; that the perpetual vibration of their foliage and swaying of their branches, whilst admitting a sufficient amount of light, serve to protect the eyes from the noonday glare; that they act as disinfectants by drawing up and absorbing the organic matters contained in the filth from which the streets of a town are never free and which, infiltrating the ground, are a frequent cause of fevers and infection; and it is asserted that on soil roads some varieties of trees both drain the road and help to hold its earthen surface together by their root-fibres.

"Those who have observed woodland roads closely know they are dry except when below the general grade of the land or actually swamped with water. At any point of temperature a tree, even in winter and without any leaves upon it, is evaporating moisture from its twigs, branches, and trunk. It must freeze very deep to prevent all root-action, and whatever moisture roadside trees may draw from the roadbed will, by so much, prevent the tendency to muddiness in any loam road well filled with tree-roots."

"Beside the draining and drying effect of tree-roots, the fibres

given to the soil by some kinds of trees (well known to ploughmen in all countries) have a most salutary effect in holding the earth together. If the soil be rich, the whole substance of the raised and rounded roadbed may be completely filled with horizontal stitches, as the housewife darns and runs the heels of stockings, thus trebling their ability to resist friction. Roots in the surface-soil are better than brush to hold up travel when they are alive and pumping water out of the ground. If we are looking for economy, nothing can be cheaper than the way a maple, elm, cottonwood, or white pine will fill the surface of an earth road with fibre. The chestnut, hickory, ash, black walnut, and beach may all be thought of in this connection, but only the close student of nature and the variety of trees adapted to different soils and situations will succeed in this branch of road-making. Yet the nation has many thousand miles of muddy highway where no other improvement seems possible."

"There is a use for the overhanging branches of trees in winter. They shade the road and permit it to freeze or remain solid when, but for the shadow, the road would be softening in the sun. The branches work in this way to prevent and protect the road from being cut in pieces. The traveller and his weary team, swamped in thawed earthen roads, are glad to reach the frozen track on the north side of a bit of woodland. And the man who would cut away roadside shades so as to let all our earth roads thaw out and settle together is very much mistaken."

Trees also serve to make the border of the road discernible at night as well as after snowdrifts, thereby warning the travellers against embankments and other dangers along the sides of the road.

918. In France, as far back as the middle of the sixteenth century, trees were planted along the royal roads. This practice has been more or less continuously followed.

During several periods it was stopped by those in authority, they being of the opinion that trees were more of a damage than a benefit. But now trees are planted along all roads having a width greater than 10 metres (32.8 feet). They are placed at distances varying from 5 to 10 metres (16.4 to 32.8 feet), in single rows upon the narrow roads, and in double rows upon the wider.

919. "The roads of Belgium are flanked on either side by two and sometimes four rows of shade-trees, which add much to the beauty of the country through which they run."

920. Financial Value of Trees.—Take two streets in all respects alike, except that one has trees well selected, set at suitable distances apart and well cared for, the other with no trees or with trees carelessly set and neglected, as frequently happens. A person wishing to purchase a residence will undoubtedly select the street having the fine trees, although he may have to pay more than many times the cost of the trees. Thus from a financial standpoint trees pay.

921. In Saxony a considerable revenue is derived from fruit-trees planted on the roadsides. The trees are cared for by the roadmen in so far as professional knowledge is not required; they remove insects, clear the tree-frames of rubbish, and water them.

In sections where fruit-trees cannot be cultivated on account of climatic causes, or where they would be liable to wanton damage and plundering of the fruit, forest-trees are planted.

The state-road fruit-trees are leased to the highest bidders, and the money received is covered into the state treasury. The lessees of the fruit-trees are held to a strict account for any damage done the trees. Ladders must be used to gather the fruit, and any battering of the trees with clubs or poles to get the fruit down is prohibited and is punishable by fine.

922. Selection of Trees.—Trees should be selected with reference to the climate, locality, quality of soil, extent of space, and circumstances of surroundings in general.

Large-growing varieties should be selected for places of great extent, smaller varieties for places of less extent. A low compact tree is not suitable for street planting.

The qualities necessary in a good street tree are that it must be hardy, must not be affected by a long-continued drought, heat must not wither it nor make it look rusty; it must be able to withstand dust, smoke, soot, foul air, and the insidious attacks of insects, and be able to recover from any malicious or accidental injury it may receive.

The tree must be of rapid growth and develop a straight, clean stem with shady foliage. It must be graceful either in full leaf or when bare, as in winter; its roots must not require too much room, and they must be able to withstand the effects of pollution or rough treatment.

As to what variety to select very little can be said; a large quantity of suitable trees exists from which one may select as local conditions or fancy may dictate.

923. Precautions to be taken in the Selection.—Whatever variety of tree is selected, the following precautions should be taken to insure its flourishing:

(1) The young tree should have been well nourished in the nursery; it should not be planted on the street until its stem is over 8 feet in height and about 3 inches in diameter. The stem should be clean and straight, and the whole tree symmetrical.

(2) The ground where a tree is to be set should be examined to see whether it is suitable for tree-growth. If it is not, the poor material should be removed and good soil substituted. The amount to be removed depends upon circumstances and can be determined by examination. A tree to flourish must have plenty of good ground in which to grow; it should be good to the depth of at least 3 feet, and an equal distance in all directions from the trunk when practicable. The amount of good soil is of greater importance than the shape it is in. The further the tree is planted from the curb the better, so as not only to give it a larger body of soil, but to lessen the risk of killing the tree by the pollution of the ground with gas from defective pipes and also excess of moisture from the gutters.

924. Distance Apart to plant Trees generally appears to be a matter of choice, but this should not be so. Trees should be placed so far from one another that at maturity they will not meet. Such distances will enable them to develop in their natural beauty. To determine the proper distance apart measure the spread of full-grown trees of the same variety as those to be planted; it will vary from 30 to 50 feet. The trees should alternate on opposite sides of the street.

925. Trees at Street-intersections.—Where streets cross at right angles or nearly so, two trees of large-growing varieties may be placed on each corner, far enough from the corner of the curb not to interfere with the catch-basin when there is one. Each tree should be placed on the tree line of one street and the fence line of the other; this will require eight trees to every intersection. The trees so planted should form a handsome mass of foliage and afford an agreeable shade where most needed. At some intersec-

tions it may not be possible to plant all the eight trees, but as many as can should be placed.

926. Protection of Trees.—Each tree should be protected with a light iron railing to prevent mischievous persons from cutting their names no or otherwise injuring the trunk.

Where it is necessary that the footpath be entirely paved the space around each tree may be arranged as shown in Fig. 177. A light stone curb is placed around the tree in a circle the diameter of which should be about 4 feet, and the curb should project above the pavement about 3 to 6 inches; this prevents people from walking on the earth, keeps the ground from becoming hard, and permits air and water to enter to the roots. Or a cast-iron grating 4 feet square may be employed for the same purpose.

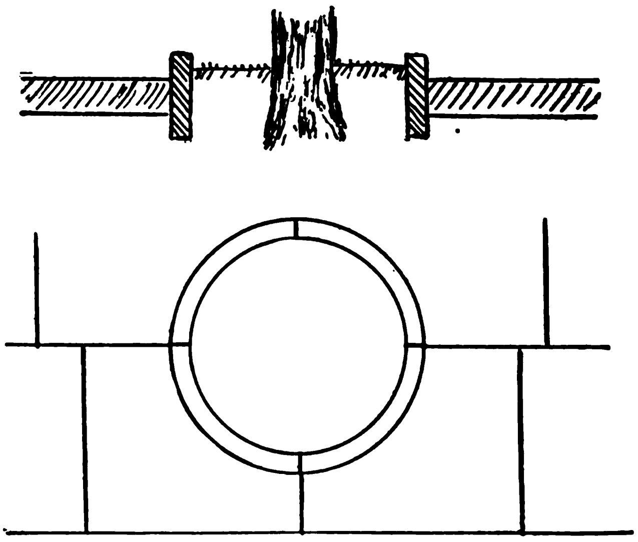


FIG. 177. PROTECTION OF TREES IN WALKS.

927. Specifications for Protection of Trees.—The contractor when directed shall protect from injury trees upon the line of the work, and the grading around them must be carefully done. The grass sodding on the sidewalks must also be protected as much as possible.

CHAPTER XXI.

STAKING OUT THE WORK.

928. THE staking out of the work consists in placing stakes in the ground to direct the workmen and define the limits of the work.

The centre line of the proposed road is marked by stakes set (usually) at distances apart of 100 feet on the straight portions, and at 15, 25, or 30 or 50 feet on curves, depending upon their sharpness; on the stakes the cut or fill at that point is marked.

929. The staking out of straight lines and simple curves of less than 100 feet radius presents no great difficulty; curves of greater radius, compound or reverse, will require to be set out by the same formula and methods as are empleyed for setting out the curves on railroads. For detailed instructions, etc., any one of the many railroad-engineer's pocket-books may be used, such as Henck's, Trautwine's, or Shunk's.

930. Side Slopes.—The setting of the slope stakes on ground that is level or nearly so at right angles to the centre line is a simple matter, the position of the stake being found by adding together the half-width of the roadway, and the base of the triangle obtained by multiplying the depth by the ratio of the slope. When the natural surface of the ground is inclined, the setting of the slope stakes is less simple. The ordinary method employed is a tentative process of combined levelling and calculation, which is nothing better than a rule of thumb. The manner of procedure is as follows: Suppose it is desired to set the stakes D and E, Fig. 178. The depth of the cutting at C is ascertained, and a point is taken on the surface where it is assumed the slope will cut; its height above AB is obtained; this height is multiplied by the ratio of the slope, and the half-width AC or CB added: if this agrees with the distance of the assumed point, that point may be taken as

correct; if not, a second trial must be made. A difference of inches will be of no practical importance.

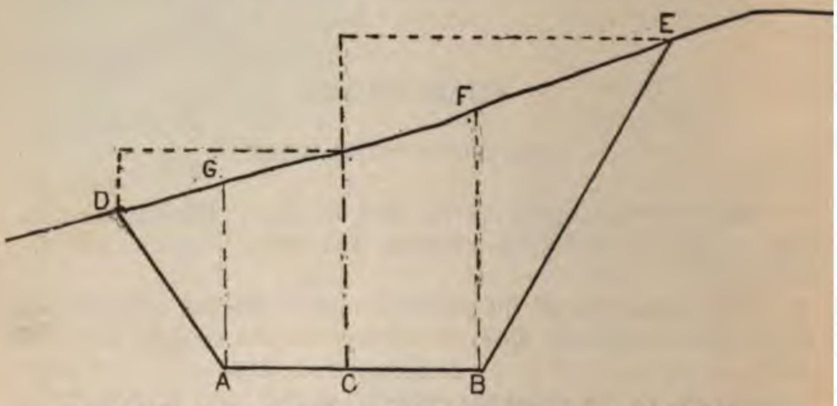


FIG. 178. MANNER OF SETTING SLOPE STAKES.

The guessing may be aided by taking levels at the points F and G, and performing the calculations as outlined above.

A more accurate and sometimes a more expeditious method is as follows:

Take a cross-section book, and on each page plot the cross-section of the ground at each station, and draw the slope lines; the exact distances can then be obtained at a glance by counting the spaces between the centre line and the point where the side slope intersects the natural surface.

Slope stakes are required at every centre stake along the line, and also where the ground is very rough at intermediate distances.

931. Setting out Culverts.—The length of a culvert which passes under an embankment is less than the distance between the bottom of the opposite side slopes, and may thus be found: From the height of the embankment H, Fig. 179, take the above ground height of the culvert h; the remainder will be the height, h_1, of the embankment: then the required length ab is equal to the top width of the embankment cd, plus the width of the base of the slopes on the top of the culvert. Thus if CD equal 30 feet, and h_1 equal 5 feet, the ratio of the slopes $1\frac{1}{2}$ to 1, the length ab will be

$$30 + (5 \times 3) = 30 + 15 = 45 \text{ feet.}$$

932. When the natural surface of the ground is horizontal, the length of any structure passing under an embankment will lie

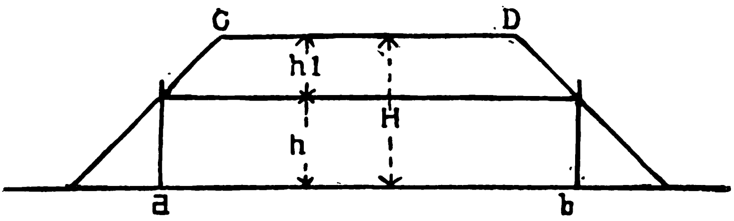
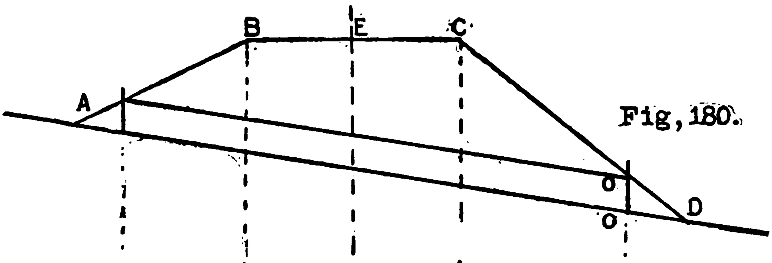
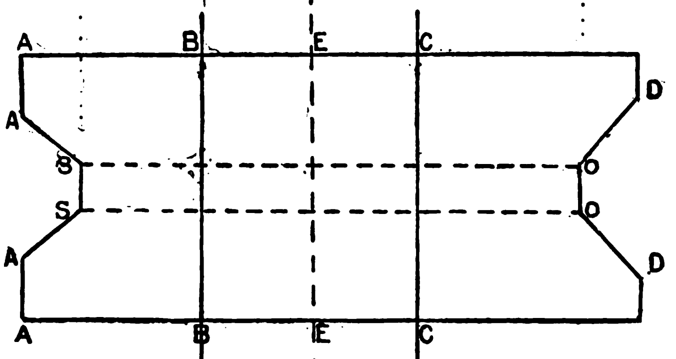


FIG. 179.

half on each side of the centre line. When the natural surface is inclined, the ends of the structure will be at different distances



Fig, 180.



Fig, 181.

from the centre line, according to the slopes of the ground. This is seen in Figs. 180 and 181, the first of which represents the section, and the second the plan, of an embankment. The lines *SS*

and OO, representing the ends of a culvert passing beneath the embankment, are seen to be at different distances from the centre line. The position of the points S and O may be found by first getting from the tables of side width the points A and D, and measuring in from these points the distances AS and DO, depending upon the slopes AB and AD. In the case of the upper end the distance of SS from A will be less than if the natural surface was level; at the lower end the distance from D to O will be greater. Having found the distances of SS and OO from the centre line, we get the position and length of the wing walls of the culvert by drawing a line from S to any desired angle to intersect the slope AA; and upon the lower side of the embankment we get, in the same manner, the lines DD, OD, the latter being of course longer than the wings upon the upper side AS, AS.

933. Setting out Bridge Work.—In laying out the abutments for bridges there are numerous cases to be considered,—as whether the bridge is on the square or on the skew, upon a level or a gradient, upon a curve or a straight line, and whether the natural surface is horizontal or inclined; the position and form of abutments and wing walls depending so much upon the various conditions affecting each particular case, that any attempt to lay down general rules for each work would be of little use.

934. Staking out Drains.—The method of setting grade marks for drains is as follows:

At every 50 feet along the line of the trench place a board a couple of feet wider than the width of the trench, bed it firmly in the earth and mark the centre line on it; then ascertain the level of the boards, calculate depth of cutting at each one, and mark it plainly on each board. To transfer the grade line to the bottom of the trench, procure a measuring-rod (say 6 feet long), subtract the depth of cutting from the length of the rod, and to the board that straddles the ditch nail a piece of board upright, the height of which above the horizontal board is equal to the difference found. This operation being performed at each board, a line stretched from the upright pieces will be parallel to the grade line, and six feet above the bottom of the trench.

935. Vertical Curves.—As stated in Article 610, the apex or meeting point of grades require to be rounded off by vertical curves, thus slightly changing the grade at and near the point of

intersection. A vertical curve rarely need extend more than 200 feet each way from that point (Fig. 182).

Let AB, BC, be two grades in profile, intersecting at station B, and let A and C be the adjacent stations. It is required to join the grades by a vertical curve extending from A to C. Suppose a

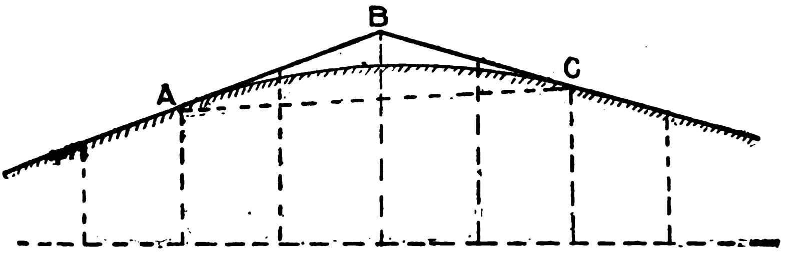


FIG. 182.

chord drawn from A to C. The elevation of the middle point of the chord will be a mean of the elevations of grade at A and C, and one half of the difference between this and the elevation of grade at B will be the middle ordinate of the curve. Hence we have

$$M = \tfrac{1}{2}\left(\frac{\text{grade } A + \text{grade } C}{2} - \text{grade } B\right),$$

in which M equals the correction in grade for the point B. The correction for any other point is proportional to the square of its distance from A or C. Thus the correction at $A + 25$ is $\frac{1}{16}$ M; at $A + 50$ it is $\frac{1}{4}$ M; at $A + 75$ it is $\frac{9}{16}$ M; and the same for corresponding points on the other side of B. The corrections in the case shown are subtractive, since M is negative. They are additive when M is positive, and the curve concave upward.

936. Staking out Contour of Street Foundations.—In order to insure the proper transverse form of street pavements, stakes should be driven across the street, the tops of which shall correspond to the intended contour. The stakes should be placed longitudinally of the street at distances not exceeding 16 feet, and transversely at distances not exceeding 10 feet. After the stakes are placed ridges of concrete may be formed along the street, as shown in Fig. 183. After the ridges or small banks of concrete are

so placed the filling of the interspaces may be proceeded with, and a straight-edge resting on the ridges will guide the workmen in keeping the concrete to the proper form; or the stakes may be placed as directed above and a thin slat nailed to their tops, the concrete filled in and made flush with the top of the slat, a straight-edge 17 feet long, its ends resting on the slats, being used for this

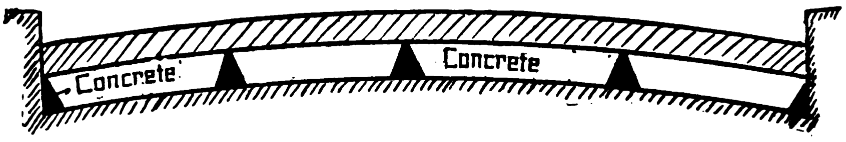


FIG. 183. MANNER OF FORMING CONTOUR OF STREETS.

purpose. After the concrete is thoroughly set the slats may be removed and the space they occupied plastered over with cement.

937. Setting Stakes for Curb.—Stakes for setting curb should be placed on the front line of the curb, with their tops at the required grade. Their distance apart should not exceed 50 feet, and on circular work will require to be closer. At street corners three stakes should be driven, one at the intersection point of the meeting curbs and one at each tangent point (Fig. 184).

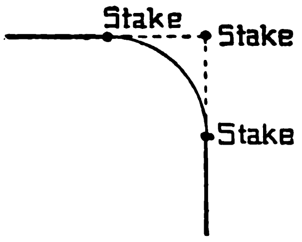


FIG. 184. SHOWING MANNER OF SETTING STAKES FOR CURBS.

938. In placing the stakes for any structure they should be placed so far outside of the work that they will remain undisturbed during the construction of the work. They must be so placed that lines stretched from any two of them will define the corner and

face of the structure (Fig. 185). Stakes for defining the boundaries of an excavation may be placed at the angles thereof.

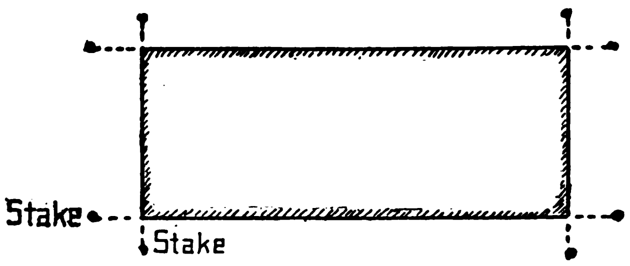


FIG. 185. MANNER OF SETTING STAKES FOR STRUCTURES.

939. Two stakes, at a sufficient distance apart upon the land, will fix any line upon the water; and two sets of stakes, upon different lines upon the shore, will by their intersection fix any point upon the water with accuracy sufficient for many purposes. For exact work, however, a transit should be employed to fix a line; and two angular instruments, in well-chosen positions, will determine any point.

940. Bench Marks.—A permanent bench or reference mark for levels should be established with care, in the immediate neighborhood of any proposed structure, from which the elevations of the various parts may be obtained. Such bench marks should also be fixed at the commencement of long cuttings, and generally at intervals of from 500 to 1000 feet along the works, a list of such elevations being entered in the engineer's note-book.

CHAPTER XXII.

SPECIFICATIONS AND CONTRACTS.

941. Specifications.—A specification or detailed description of the various works to be carried out is always attached to a contract, and is prepared before estimates are called for. The prominent points in connection with specifications are as follows:

(1) Description of the work.
(2) Extent of the work.
(3) Quality of the materials.
(4) Testing of the materials.
(5) Delivery of materials.
(6) Character of the workmanship.
(7) Manner of executing the work.
(8) Time of commencement.
(9) Time of completion.
(10) Manner and times of payment.
(11) Penalties for infraction.
(12) Such general instructions and stipulations as may be found necessary in each case.

Attention to these points and a clear and accurate description of each detail (leaving nothing to be imagined) will not only materially contribute to the rapid and efficient execution of the work, but will avoid all future misunderstandings.

942. Concerning Tests of Materials.—While proper tests should always be stipulated, yet if they are carried to an extreme degree, as frequently happens, they defeat their own object. When it becomes impossible to carry out certain unreasonable demands, the alternative is to evade them as much as possible; and it must always be borne in mind that the more stringent the demand, the greater the difficulty in enforcing it.

943. Contracts.—A good, clear, and comprehensive contract is a difficult thing to write, but it should be "common-sense" from beginning to end, and should be the joint production of both engineering and legal ability, neither sacrificing the one feature to the other.

GENERAL SPECIFICATIONS.

The following specifications, in conjunction with those given throughout the work, will aid in preparing specifications for the different works connected with highways.

944. Clearing.—The land will be cleared to the width of feet on each side of the centre line, and on each section must be entirely completed before grading is commenced.

The clearing must be done in such manner that all useful timber may be saved. Trees of large dimensions shall be trimmed and put into the most profitable shape for the market; when so trimmed they shall be piled in such places along the line of the road as the engineer may designate.

Brushwood, stumps, tree limbs, etc., must not be cast upon the adjacent land, but shall be formed into piles and burned; stumps and other material that will not burn, must be removed from the work and disposed of by the contractor. All brush or trees accidentally or otherwise thrown upon the adjacent lands must be taken off and disposed of as above described. The land when cleared must be left in a clean condition, and the contractor will be held responsible for all damage to crops, fences, fruit-trees, and timber of adjacent owners.

945. Close Cutting.—Where embankments are to be formed more than one foot in height, the stumps shall be chopped close to the ground.

946. Grubbing.—Where excavations do not exceed 2 feet in depth, or embankments one foot in height, all stumps shall be grubbed out. The catch-water drains, side ditches, and off-take drains shall be grubbed wherever required.

947. Grading.—Grading will include all excavations and embankments required to form the roadway, all excavations and embankments required for altering the level of intersecting roads. Excavations for the foundations of all structures, excavations for all trenches and ditches, excavations required for the altering of

the channels of streams, etc., and all other excavations and embankments that may be required for the full completion of the road.

The grading shall be executed in accordance with the lines and grades given by the engineer. The portions which are above grade are to be excavated, and such and so much of the excavated material as may be suitable for the purpose, and as may be necessary, shall be filled in those parts which are below the grade lines. The material excavated, not so used for filling, shall be placed in spoil-banks at such points as the engineer designates, or it may be removed from the line of the work by the contractor for his own use and benefit, if so directed.

Where embankments are to be formed of a height less than 3 feet, all top-soil and vegetable matter must be excavated to such depth as the engineer may direct. The material so excavated will be piled up outside of the embankment lines, and afterwards used to cover the slopes of embankments and cuttings; the surplus that remains after completing this work shall be removed and placed in spoil-banks at such places as will be designated by the engineer, or it may be removed by the contractor for his own use and benefit. In places where the embankments exceed 3 feet in height the perishable matter shall be removed, but no excavation done unless specially ordered by the engineer.

All sloping ground covered with pasture shall be deeply ploughed over the base of the embankments before the latter are commenced. On slopes which have been covered with timber the slope shall be cut into steps before the embankment is commenced.

948. Formation of Embankments.—Embankments of a height less than 3 feet shall be made by horses and carts. Embankments of greater height may be formed by tipping from dump-cars travelling on a track.

The embankments will be formed to such height above the sub-grade as the engineer may direct, to provide for shrinkage, compressions, washing, and settlement, and they must be maintained to the required height, width, and shape until accepted. Whenever embankments are made from side ditches, the width of the berm to be left at the foot of the slopes will be given by the engineer.

In the formation of embankments no mud, muck, vegetable

matter, tree stumps, or other materials which the engineer may deem unsuitable, will be allowed to be used. Such material must be removed from the line of the work and disposed of as the engineer may direct.

After completion, the slopes of all cuttings and embankments will be covered to a depth of 6 inches with the loam and vegetable soil previously reserved for this purpose, or such shall be obtained from such places as the engineer may direct.

The slopes of embankments will generally be 1½ to 1, of earth excavations 2 to 1, of rock excavations 1 to 1; and no allowance for excavations outside the limits of these slopes will be made unless specially ordered by the engineer.

The widths, slopes, and other dimensions may be varied at any time by the engineer to suit circumstances.

In the event of slips occurring in excavations, the contractor will remove the débris and reslope the work. If the slips occur through carelessness on the part of the contractor, no allowance for the removal or reshaping will be made; but if they occur through unavoidable causes, he will be paid for it as loose rock or as earth, according to the class to which it may appear to the engineer to belong.

Rock shall be excavated to a depth of two feet below the subgrade level and the space refilled with stone broken to a size not exceeding 2½ inches.

In the event of work being proceeded with in winter, no snow or ice will be placed in embankments or allowed to be covered up in them, and all frozen earth must be excluded from the heart of the embankment.

949. Earth-work Measurement and Classification.—All earthwork shall be measured in excavation, and will be classified under the following heads, viz., earth, loose rock, solid rock.

Earth will include clay, sand, gravel, loam, decomposed rock, and slate, stones and bowlders containing less than one cubic foot, and all other matters of an earthy nature, however compact they may be.

Loose rock will include all bowlders and detached masses of rock measuring more than one cubic foot and less than one cubic yard; also hardpan, compact gravel, sandstone, and all other materials of a rock nature (except solid rock) which may be

loosened with the pick, although blasting may be resorted to in order to expedite the work.

Solid rock will include all rock found in place in ledges, and in masses or bowlders measuring more than one cubic yard, and which can only be removed by blasting, which fact will be determined by the engineer.

950. Drains.—At such places as may be designated by the engineer, drains will be formed in the following manner: the trenches will be opened to the width and several depths given by the engineer. In the trenches so opened drains of tiles will be constructed, as directed by the engineer.

The tiles furnished shall be the best quality of clay or terra-cotta, manufactured expressly for drainage purposes; they shall be in lengths of not less than one foot, and shall be of uniform diameter throughout. A pipe of larger diameter, broken in half, will be used for collars; the pipes will be laid true to grade and the trenches filled in with round field stones. The stones must not be thrown in, but shall be laid in carefully by hand, the largest stones being used to wedge the pipes in place; on top of the stone filling place good sods, with the grass side down. Silt-basins will be constructed of brick, of the forms and dimensions shown on plans, at the points designated by the engineer.

951. Catch-water Ditches.—Catch-water ditches will be excavated at the top of the slope of all excavations on the up-hill side only; they shall be excavated not closer than 6 feet to the edge of the slope; they shall be excavated on the lines and to the grades given by the engineer.

952. Off-take Ditches.—These ditches will be excavated wherever directed by the engineer, and will have such form and dimensions as he may direct.

The contractor shall also excavate and form all other drains and ditches which the engineer may deem necessary for the proper drainage of the road.

953. Rip-rap.—In cases where slopes require protection from the action of water, the protection works will be constructed of brush or stones, and will be carefully performed in such manner and of such dimensions as the engineer may direct.

954. Retaining, Breast, Slope, and Parapet Walls.—These walls

will be constructed at such places and in such manner as may be directed by the engineer.

955. Culverts formed of earthenware, cast-iron pipe, stone laid dry or in mortar, will be constructed wherever directed by the engineer. Their form and dimensions shall correspond with the detailed plans prepared therefor.

MASONRY.

Stone masonry will be classified as follows:

956. First-class Masonry shall be built of sound stone, of a quality to be approved by the engineer; it will consist of large rectangular stones, with the beds dressed parallel throughout, and the vertical sides hammer-dressed so as to form quarter-inch joints; the stones will be left quarry-faced except when otherwise ordered; rock-faced stones to have a one-inch chisel-draught cut on all four edges of the face, and no face projection greater than 3 inches.

The rise of the courses of first-class masonry will not be less than 12 inches, and may range up to 24 inches, the thinnest courses being invariably placed towards the top of the work; the stones in adjacent courses shall break joints by at least one foot.

Headers shall be built in every course not further apart than 6 feet; they will have a length in the face of the wall of not less than 24 inches, and they must run back at least $2\frac{1}{2}$ times their height; when they will not allow this proportion, they must pass through from front to back. Stretchers shall have a minimum length in the face of the wall of 30 inches, and their breadth of bed shall be at least $1\frac{1}{2}$ times their height. First-class masonry will be laid in Portland cement mortar, and each course must be thoroughly grouted before the next course is started. Each stone shall be cleaned and dampened before being set. Improperly dressed stones must be recut before placing in the wall, as no hammering will be allowed after the stones are set.

First-class masonry will include all dimension stone, such as coping, cap-stones, bridge seats, and parapets, abutments, and piers of large bridges.

957. Second-class Masonry will include retaining-walls, abutments, wing walls and parapets of minor bridges, and head walls on box culverts. It will consist of broken range-work, built of such stone as may be approved by the engineer; the stones shall be dressed

to horizontal beds and vertical joints; the face shall be "rock face," with edges pitched to line, with no face projections exceeding 2 inches. At least one third of the stones must be headers evenly distributed through the wall; the mortar joints shall not exceed one half-inch in thickness. All vertical joints must be broken by at least 6 inches. No stone will be allowed in the face of the wall which has a less area than 72 square inches. Quoin stones shall have a chisel-draught one inch wide cut on each side of the angle.

The backing and foundation will be of large sound stones, roughly squared, no stone to measure less than 2 cubic feet. The broadest bed will be laid underneath, and must have a good bearing on the stones below. The stones shall be laid in full mortar beds, well bonded with each other and with the face stone, and with all spaces filled with small stones and spalls, well grouted.

No stone shall be cut on the wall, and stones once bedded shall not be removed unless directed by the engineer.

The foundation course shall be of large stones not less than 12 inches in thickness and 8 feet area of bed, and when the wall is 4 feet or less in thickness shall extend from front to back.

The mortar employed for second-class masonry will be of Rosendale cement, in the proportion of 1 of cement to 2 of sand. Portland cement will be used wherever directed by the engineer.

958. Third-class Masonry.—Masonry of this class will generally be used for box culverts, retaining and slope walls, and for backing for first-class masonry. It shall consist of sound stones laid on their natural beds, and roughly squared where used for face work.

The walls shall be carried up in courses ranging from 15 to 18 inches in height; each course shall be well bonded, having a header at every 3 feet. Not more than one third of the stones shall be less than 9 inches thick, or contain less than two cubic feet, and no stone shall be less than 6 inches thick. The stones shall be laid in Rosendale cement mortar, and each course well grouted.

959. Fourth-class Masonry will consist of stone laid dry, and will be used for box culverts, retaining, slope, breast, and parapet walls, and paving of box and arch culverts.

960. First-class Arch-culverts shall be built in accordance with the specifications for first-class masonry, with the exception of the arch sheeting and ring-stones. The ring-stones shall be so dressed that when laid their beds will radiate truly from the centre of the circle. The ring-stones and sheeting shall not be of less thickness

than 10 inches on the soffit, and shall be dressed the full depth of the bed, so as to form joints not exceeding three eighths of an inch; each stone must break joints with its fellow by at least 10 inches. Arch stones to be full bedded in mortar, and each course afterwards thoroughly grouted. The face stones to be rock-face, with a one-inch chisel-draught around the edges.

961. Second-class Arch-culverts.—Arch-culverts of 8 feet span and under shall be constructed of suitable flat bedded stones, ranging, according to the span, from 16 to 24 inches deep, and with a minimum length of from 16 to 24 inches, and 5 to 6 inches in thickness on the soffit. They must invariably extend through the entire thickness of the arch; each stone to be well and closely fitted so as to give half-inch joints, and to break joints with its fellow 9 to 7 inches. The whole to be laid in thin cement mortars, and each course well grouted immediately after being laid.

The face-stones of the arch to be as nearly uniform in depth as possible, of large size, and neatly incorporated with the perpendicular face of the masonry. The keystones to be 10 or 12 inches on the soffit, to have a chisel-draught around their edges, and to project beyond the face of the wall 2 or 3 inches. The side and wing walls will be of second-class masonry.

The extrados of all arches shall be flushed with cement mortar three inches thick, levelled up and rounded to a moderately even and smooth surface.

962. Centring.—Centres of arches must in all cases be well formed, of ample strength, securely placed in position, and in every respect conform to the requirements of the engineer. The ribs must not be placed further apart than 3 feet in any case. The lagging shall be 3 inches thick; the supports of centres shall be substantial and well constructed, and they must be provided with proper wedges for easing centres when required. Centres shall not be struck without permission from the engineer.

963. Wing Walls will generally be of first-class masonry, laid up in steps, each step covered with a hammer-dressed coping.

964. Parapets of masonry structures will be of first-class masonry, covered with hammer-dressed coping.

965. Laying Masonry in Freezing Weather.—No masonry is to be built in freezing weather, except by permission of the engineer. If such permission is given the mortar shall be made by either of the following methods:

Make a mortar of one part of hydraulic lime and three parts of sand, mix thoroughly, and allow it to stand in a heap covered with stable manure until used, to prevent freezing.

Mix mortar for use with ordinary cement in the proportions of one to three. Both mortars to be saturated with brine in the final mixing. Or,

Dissolve one pound of rock salt in 18 gallons of water when the temperature is at 32 degrees Fahr., and add one ounce of salt for every degree lower of temperature, or enough salt, whatever the temperature may be, to prevent the mortar freezing.

No masonry laid in freezing weather to be pointed until spring.

966. Pointing.—All outside joints of first- and second-class masonry shall be raked out to a depth of one inch, and neatly pointed with a mortar made of one part Portland cement and one part of sand.

967. Grouting.—Each course of masonry as laid shall be grouted with a mixture of two parts of cement to 3 parts of sand, no more water being used than that necessary to give the required fluidity.

968. Brick Masonry.—The bricks used shall be of the best quality, hard-burned entirely through, regular and uniform in shape and size. Soft or underburned bricks will not be allowed in the work. The bricks shall be laid in cement mortar made as directed. Every brick shall be laid in a full bed of mortar on bottom, sides, and ends, which for each brick is to be performed at one operation. In no case is the joint to be made by working in mortar after the brick is laid. The joints shall not exceed $\frac{3}{8}$ of an inch, and none shall be less than $\frac{1}{4}$ of an inch, and shall be neatly struck or flush-pointed. Every sixth course to be headers. No "bats" shall be used except in the backing of walls, where a moderate proportion (to be determined by the engineer) may be used, but nothing smaller than half-bricks will be allowed.

The bricks will be inspected and culled on delivery, and those condemned must be at once removed.

The bricks must be thoroughly wet just before laying.

In forming arches the bricks must be laid in concentric rings, each longitudinal line of bricks breaking joints with the adjoining lines in the same ring and in the ring under it.

969. Dry Walls.—Retaining, slope, parapet, and breast walls of

dry stone will be constructed where directed. The stones for this class of work must be sound, flat, bedded stones. No round or cobble stones will be allowed. Not more than one third of the stones shall be less than one foot thick, and no stone shall be less than six inches thick or have a bed area of less than four feet. The stones shall be set horizontally on their largest bed, and so well bedded and fitted as to require neither spalls nor wedges to keep them in place. All walls shall be covered with a hammer-dressed coping of the dimensions shown on the plans.

970. Dry Box-culverts.—The bottom shall be paved with good sound stone closely set on edge under the walls as well as the waterway. The side walls shall be built of large well-shaped stones well bonded and joints well broken. No stone shall have a less area of face than one square foot. There shall be one header to every three stretchers, and the header must pass entirely through the wall. The covering-stones must be entirely sound and wide enough to extend at least two thirds across either wall.

The end walls of box-culverts shall be laid up in second-class masonry and finished off in accordance with the plans. The coping must be of proper and uniform thickness, neatly hammer-dressed on top and face.

971. Pipe-culverts.—Culverts of salt-glazed earthenware or cast-iron pipe shall be constructed at such points as the engineer may designate. The ends of said pipes will be carried by head walls of either brick or stone masonry covered with stone coping. The form and dimensions of these structures shall correspond to the plans prepared therefor.

The earthenware pipe shall be of the quality known as culvert-pipe. It shall be sound and well burned throughout, free from cracks, flaws, fire-checks, and other imperfections, and shall be of uniform thickness throughout and shall have not less than the following weights:

Internal diameter.	Weight per foot.
6 inches	15 pounds
9 "	28 "
12 "	40 "
15 "	60 "
18 "	80 "
20 "	90 "
24 "	130 "

The joints shall be closed with cement-mortar.

Cast-iron pipe shall be used wherever directed by the engineer, and shall be obtained from a foundry approved by him. It shall be of the diameters and thickness ordered, will be laid in the same manner as earthenware pipe, and the joints calked with lead if so ordered.

972. Cement.—All cement furnished must be of some well and favorably known brand, and shall be approved by the engineer. It shall be delivered in barrels or equally tight and safe receptacles, and after delivery must be protected from the weather by storing in a tight building or by suitable covering. The packages shall not be laid directly on the ground, but shall be laid on boards raised a few inches from it. To insure its good quality it shall be subjected to the following tests, and every cask or lot of cement rejected by the engineer shall be conspicuously marked "condemned," and shall be removed from the site of the works; and, after rejection, should any of the cement so rejected be found to have been used, the work where it has been used shall be taken down and replaced with cement of the proper quality without extra compensation.

The supply of cement must be so gauged that a sufficient quantity will be kept on hand to allow ample time for the tests to be made without delay to the work of construction.

973. Cement Tests.—The Rosendale cement must stand a tensile strain of 50 pounds per square inch of sectional area on specimens mixed to a stiff paste and allowed to set thirty minutes in air and twenty-four hours under water, and of 90 pounds on specimens allowed to set seven days under water, and shall be ninety per cent fine when tried with a sieve having 2500 meshes to the square inch. It must take not less than twenty-five minutes to bear the light wire, that is, a weight of four ounces on a wire one twelfth of an inch in diameter.

Portland cement shall be tested in the same manner and the requirements for fineness will be the same, but specimen briquettes will be required to resist without fracture a tensile strain of at least 175 lbs. per square inch at the expiration of three days, and at the expiration of seven days to show an increase of at least 50 per cent over the strength at three days, but it must bear a minimum strain of 350 lbs. per square inch at the end of seven days.

974. Sand.—The sand used for making mortar shall be sharp,

clean, and free from loam and vegetable matter. If sand of the required quality cannot be found in natural beds on the line of the work, it shall be furnished by the contractor. The sand shall be screened and washed if so ordered by the engineer.

975. Water.—The water employed for mortar shall be fresh and clean, free from mud or other objectionable matter. Sea-water may be used if permission is given by the engineer.

976. Mortar shall be composed of two parts of sand and one part of cement, mixed thoroughly dry and tempered to the required consistency.

When Used.—It shall be used as soon as made, and any mortar that may have taken a "set" while unused shall be wasted.

Variation in Proportion.—No variation from the above proportions will be permitted unless to make the mortar richer when required in special cases.

Tempering.—The thorough mixing and incorporation of the materials will be insisted upon. The dry cement and sand shall be turned over and mixed with shovels by skilled workmen not less than ten (10) times before the water is added; after adding the water, the paste shall be again turned over and mixed by skilled workmen not less than six (6) times before it is used.

Boxes.—Tight mortar boxes will be provided, and no mortar shall be made except in such boxes.

977. Concrete, how Composed.—Concrete shall consist of angular fragments of sound, durable stone or hard-burnt brick, which shall be cleaned and thoroughly freed from dust and dirt, and broken so as to pass in any direction through a ring two (2) inches in diameter, and of hydraulic cement and sand, in the following proportions by volume:

Cement	1 part
Broken stone	5 parts
Sand	2 "

Mixing.—These materials shall be intimately incorporated on the mixing-board or in a mechanical mixer, and after proper tempering shall be deposited carefully in place and thoroughly rammed until the surface is floated.

Period of Repose.—The concrete so laid shall be left without disturbance or shock for at least twenty-four (24) hours.

Variation in Proportions.—The above proportions shall be varied without extra compensation upon the order of the engineer and to his entire satisfaction.

Expeditious Operation.—The whole operation of mixing and laying each batch of concrete shall be performed as expeditiously as possible, with the use of a sufficient number of skilled men.

978. Foundation Excavation.—Foundation-pits shall be excavated to such depths as the engineer may deem proper for the safety and permanence of the structure to be erected.

979. Artificial Foundations.—Foundations of piles, timber, plank, and concrete shall be prepared of such dimensions and in such manner as the engineer may direct, and the materials used shall conform in quality, etc., to the requirements stated for the respective kinds.

980. Timber.—The timber furnished shall be sound, straight-grained, well seasoned, and free from sap, large knots, shakes, and wanes. Knotty timber will not be allowed in the work where such would impair its strength.

981. Piles.—The piles shall be of sound, straight-grained timber from which the bark has been removed; they shall measure not less than 8 inches in diameter at the small end, nor be less than 28 feet long. They may be driven with any approved form of pile-driver or by the "hydraulic jet:" if they are driven by this latter method, they shall be constantly loaded with a weight of 2000 lbs. They shall be driven, by whichever method adopted, until they do not move more than one-half inch under the blow of a hammer weighing 2000 lbs. and falling 30 feet.

982. Cofferdams.—Where cofferdams are required for foundations, they shall be constructed in the manner directed by the engineer, and all pumping, bailing, and draining shall be performed as required and directed by the engineer.

983. Wrought-iron.—All wrought-iron work furnished to be of the specified form and dimensions. The wrought-iron used shall be the best refined iron; it shall be tough, close-grained, highly fibrous, and when broken shall show a blue-gray fracture. It shall bear a high welding heat, and a cold bar must bend through 90 degrees without sign of fracture; the tensile strength to be not less than 50,000 lbs. per square inch of sectional area when tested in large and long lengths. The reduction of breaking area shall average 25

per cent, and the elongation of the bar before rupture shall be at least 15 per cent. Iron subjected to compressive strain to have an elastic limit of not less than 25,000 lbs. per square inch.

984. Cast-iron.—All cast-iron work to be of the specified form and dimensions; the iron to be gray iron, of uniform color and structure, with medium grain, sharp bright fracture, tough texture, and a low percentage of graphite. It shall be clean and free from sand, scoria, cold-shuts, blow-holes, blisters, or other injurious defects. Sample pieces 1 inch square, cast from the same heat of metal in sand-moulds, shall be capable of sustaining, on a clear span of 4 feet 8 inches, a central load of 500 pounds when tested in a rough bar. A blow from a 4-pound hand hammer shall produce an indentation on a rectangular edge of the casting without flaking the metal.

GENERAL STIPULATIONS APPLICABLE TO ALL CONTRACTS.

The following stipulations are applicable to all classes of work and should be inserted in all specifications, being varied, of course, to suit each particular case.

985. Interpretation of Specifications.—In case of ambiguity of expression in the specifications, or doubt as to the correct interpretation of the same, the matter shall be submitted to the engineer, whose decision shall be final.

986. Omissions in Specifications.—Any work or materials that may have been accidentally omitted in the description of the work, but which is clearly implied, shall be furnished by the contractor the same as if it had been specifically stated.

987. Engineer defined.—Wherever the word "engineer" is used it refers to the chief engineer or his authorized assistants, by whom all explanations and directions necessary for the satisfactory prosecution and completion of the work described in these specifications will be given.

988. Contractor defined.—Wherever the word "contractor" is used it refers to and means the party or parties who shall have duly entered into contract with the   of   to perform the work; their duly authorized agents or legal representatives.

989. Notice to Contractor.—Any written notice to the contractor which may be requisite under these specifications may be served on

said contractor either personally or by mail, or by leaving the same at his last known place of residence.

990. Preservation of Engineer's Marks, etc.—All engineer's marks and stakes after location shall be carefully preserved without disturbance until permission for their removal or erasure shall be given, and every facility must be furnished for the staking out, etc., of all work to be done under these specifications.

991. Dismissal of Incompetent Persons.—Any incompetent person or persons who may be employed on the work shall be removed on the requisition of the engineer; and no person so removed shall thereafter be employed upon any portion of the work.

992. Spirituous Liquors.—Contractors are not to give or sell or suffer any one to give or sell or keep any ardent spirits on any part of the work or in any boarding-house or building under his control.

993. Quality of Materials.—All materials furnished and used under these specifications must be of the best quality of their respective kinds, free from any and all defects which in the judgment of the engineer may render them unfit for use. Rejected material must be at once removed from the works or conspicuously marked "condemned." If condemned material is used in any part of the work, the same shall be removed and replaced with materials of the quality required by these specifications.

994. Samples.—Before any materials are used, samples thereof shall be furnished the engineer by the contractor. Said samples, if approved, shall remain in the engineer's office and be used as the standard with which all like materials furnished under these specifications must agree.

995. Deviations from Plans and Specifications.—No deviations from the specifications or detailed plans will be allowed, unless a written permission shall have been previously obtained from the engineer.

996. Right reserved to alter Details.—The engineer, during the progress of the work, may, by giving written notice to the contractor, alter any of the details of construction in any manner that may be found expedient or suitable; such alterations shall not invalidate the contract, and the contractor must adopt and execute the same as if they were part of the original contract, and at the completion of the work an allowance will be made for such alterations, etc., either for or against the contractor as the case may be, and the value of such alterations will be estimated by the engineer

from the schedule of prices attached to the contract, or should it not apply, the equitable amount will be estimated by the engineer.

997. Inspectors.—The work under these specifications is to be prosecuted at and from as many different points on the line of the work as the engineer may from time to time determine, and at each of said points inspectors may be placed on the day designated for the commencement of the work thereat. Whenever any work is in progress at or from one or more points at a time, an inspector may be appointed by the engineer to supervise each subdivision of the same, viz., for the inspection of the material, excavation, preparation for the foundation, the laying of the pavement, etc.

998. Defective Work.—The contractor will be held responsible for the faithful execution of the work in accordance with the specifications. Any defective work that may be discovered by the engineer or his appointees before the final acceptance, or before final payment shall have been made, shall be removed and replaced by work and materials which shall conform to the spirit of the specifications; the fact that the inspector or other person in charge may have overlooked such defective work shall not constitute an acceptance of the same.

999. Measurements.—The different classes of work will be measured as follows:

Clearing and *grubbing* by the acre.

Excavation in all classes of earth, rock, etc., and in all situations, including ditches, foundations, altering the channel of water-courses, borrow-pits, etc., by the cubic yard; the measurement shall invariably be made in excavation. If any case should arise where this may be found impossible, then the engineer shall determine the quantities, making all proper allowances, of which he will be the judge.

Overhaul.—The contract price of excavation shall be taken to include the whole cost of hauling, except only extreme cases which may involve a haul of more than eight hundred (800) feet. For every hundred feet over eight hundred (800) and up to twenty-five hundred (2500) the contractor will be allowed at the rate of one cent per cubic yard; that is to say, in the event of the haul being in any case 2500 feet, seventeen cents (17) per yard will be added to the schedule rate, and will be the maximum allowance for overhaul in any case.

The price stipulated for excavation of the several denominations, together with the price of overhaul in extreme cases, shall be the total price for excavating, loading, removing, depositing, and shaping all the material. In a word, the rates and prices stipulated in the contract must be understood to cover every contingency,—the furnishing of all labor, material, power, and plant, the cost of finishing up cuttings and embankments, the dressing and draining of borrow-pits, and the dressing of slopes to the required angle, and the completing of everything connected with the grading in a creditable and workmanlike manner, in accordance with the directions and to the satisfaction of the engineer.

Masonry of all kinds and classes (stone and brick) by the cubic yard in place.

Timber, lumber and plank, of all kinds and for all purposes, by the foot, board measure, in place.

Piles by the lineal foot in place.

Culvert and Drain-pipe of all classes by the lineal foot in place.

Stone, Brick, and Pole Drains by the lineal foot in place.

Concrete by the cubic yard in place.

Curbing by the lineal foot in place.

Gutters by the square foot in place.

Crossing or Bridge Stones by the square foot in place.

Catch-basins by number as completed, including all appurtenances and connections.

Bridges by the lineal foot in place.

Pavements.—All classes of pavements will be measured by the square yard in place; and the area occupied by the rails of street railways will be deducted, but the space occupied by manhole heads and catch-basins, when not exceeding one square yard each, will be included.

The several measurements will be made and computed by the engineer, and his final return of the several amounts shall be the only valid account of the work done and materials furnished. All previous estimates upon which partial payments may have been made are merely approximate, and subject to the correction of the final return.

1000. Partial Payments.—Monthly estimates shall be made during the progress of the work, and payments to the amount of 80

per cent thereof will be made, the retained percentage not being due or payable until the final completion of the work. These monthly estimates do not constitute an acceptance of the work, the final estimate and formal acceptance constituting the only valid acceptance of the whole or any part of the work.

1001. Commencement of the Work.—The work to be done under these specifications shall be commenced on such day and at such place or places as the engineer may direct. Failure to so commence without a good and valid reason therefor will be authority for the to declare the contract forfeited, and the said may proceed with the execution of the work in such manner as may be deemed proper.

1002. Time of Completion.—The work shall be prosecuted in such manner as to complete it in accordance with the specifications on or before the expiration of working days. Should the execution of the work be delayed in consequence of any act or omission on the part of the , the condition of the weather, or by any circumstances so unusual that they could not be foreseen previous to or avoided during the construction of the work (all of which shall be determined by the engineer, who shall certify the same in writing), the time during which the work was so suspended shall be excluded, and the time extended by a corresponding number of days.

But neither an extension of time for any reason beyond the date fixed for the completion of the work, nor the acceptance of any part of the work comprised in these specifications subsequent to the said date, shall be deemed to be a waiver by the said of the right to abrogate the contract for abandonment or delay in the manner herein provided.

1003. Progress of Work and Forfeiture of Contract. — The reserves the right to declare the contract forfeited, if at any time it should appear to the engineer that the work or any part thereof is being unnecessarily delayed, or that the contractor is wilfully violating any of the conditions of the contract, or is executing the same in bad faith, or if the said work be not fully completed within the time named for its completion; he shall have power to notify the contractor to discontinue all work or any part thereof, by a written notice to be served upon the contractor either personally or by leaving said notice at his residence or with his

agent in charge of the work. And thereupon the contractor shall discontinue said work or such part thereof, and the engineer shall thereupon have the power to place such and so many persons as he may deem advisable, by contract or otherwise, to complete the work, or such part thereof, and to use such materials as he may find upon the line of said work, and to procure other materials for the completion of the same, and to charge the expense of said labor and materials to the aforesaid contractor; and the expense so charged shall be deducted and paid by the , out of such moneys as may be then due, or may at any time thereafter become due said contractor on account of work performed under these specifications; and in case such expense is less than the sum which would have been payable if the same had been completed by the said contractor, he shall forfeit all claim to the difference; and in case such expense shall exceed said sum, he shall pay the amount of such excess to the .

1004. Damages for Non-completion.—The contractor shall pay to the , as damages for non-completion of the work within the time stipulated for its completion, the sum of $100 for each and every day which may exceed the said stipulated time for its completion, which said sum of $100 per day is hereby, in view of the difficulty of estimating such damages, agreed upon, fixed, and determined by the contractor and the as the liquidated damages that the will suffer by reason of such default, and not by way of penalty; and the is hereby authorized to deduct said sum of $100 per day from the moneys which may be due or become due said contractor for work under these specifications.

1005. Evidence of the Payment of Claims.—In case of any legal claims being filed with the against the contractor for labor or materials furnished under these specifications, the said shall retain the whole or so much of such moneys as may be due or to become due the contractor as may be considered necessary to meet the lawful claims of such persons, until the liabilities shall be fully discharged and such notice withdrawn.

1006. Protection of Persons and Property.—The contractor shall during the progress of the work use all proper precautions by good and sufficient barriers, guards, temporary bridges, etc., for the prevention of accidents, and at night he will put up and keep suitable and sufficient lights, and he will indemnify and save harmless the

against and from all suits and actions, of every name and description, brought against it, and all costs and damages to which the said may be put for or on account or by reason of any injury or alleged injury to the person or property of another, resulting from negligence or carelessness of the contractor, his agents or employees, in the performance of the work, or in guarding the same, or from any improper materials used in its prosecution, or by or on account of any act or omission of the contractor, his agents or employees; and the shall retain the whole or so much of the moneys due or to become due by reason of the work under these specifications as may be considered necessary, until all such suits or claims for damages as aforesaid shall have been settled and satisfactory evidence to that effect is furnished.

1007. Bond for Faithful Performance of the Work.—The contractor shall execute with his sufficient sureties a bond in the sum of thousand dollars for the faithful performance of the work in accordance with the requirements of the specifications.

1008. Power to Suspend Work.—The prosecution of the work may be suspended for such periods as the engineer may from time to time determine. No claim or demand shall be made by the contractor for damages by reason of such suspensions in the work, but the period of such suspensions will be excluded in computing the time limited for the completion of the work. During such suspensions all materials delivered upon but not placed in the work shall be neatly piled or removed so as to not obstruct public travel. The wages of watchmen retained for the public protection during the period of suspension will be allowed.

1009. Loss and Damage.—All loss and damage arising out of the nature of the work to be done under these specifications, or from any unforeseen obstructions or difficulties which may be encountered in the prosecution of the same, or from the action of the elements, or from incumbrances on the line of the work, shall be sustained by the contractor.

1010. Miscellaneous Work.—If any work or service be required to be done which in the opinion of the engineer does not come within the class of work to be measured under the contract, he shall be at liberty to direct the contractor to perform the same by day's labor, and the contractor when required by him shall furnish such force and materials and perform such work in the manner

directed, and he shall be paid the reasonable and actual wages of the men as ascertained by the timekeeper and the actual value of all materials furnished, together with fifteen per cent of the total amount for the use of tools and profit. The engineer shall be at liberty to discharge any inefficient or unsuitable workmen who may be placed on such work, and the work so performed will be subject to his approval before payment is made therefor.

1011. Cleaning up.—All surplus materials, earth, sand, rubbish, and stones, are to be removed from the line of the work as rapidly as the work progresses. At any time within one month after the completion of the work, if so required by the engineer, all material shall be swept into heaps and removed from the line of the work; and unless this be done by the contractor within forty-eight hours after being notified so to do to the satisfaction of the engineer, the same shall be removed by the   , and the amount of the expense thereof shall be deducted out of any moneys due or to become due to the contractor under these specifications.

1012. Personal Attention.—The contractor shall give his personal attention to the faithful prosecution of the work, shall not sublet the same or any part thereof without the consent of the   , nor will he assign by power of attorney or otherwise any of the moneys payable under these specifications.

1013. Payment of Workmen.—The contractor shall punctually pay the workmen who shall be employed on the work comprised in these specifications, in cash current, and not in what is denominated "store" pay.

1014. Prices.—The prices stated by the contractor in his tender and stipulated in the contract must be understood to cover every contingency, the furnishing of all labor, materials, power, and plant which may be required for the performing and completing of the work described in these specifications (and for maintaining the same in good order for a period of six months).

1015. Payments, when Made.—The contractor shall not be entitled to demand or receive payment for any portion of the work done or materials furnished under these specifications until the same shall be fully completed in the manner set forth, and such completion duly certified by the engineer in charge of the work, and until each and every of the stipulations herein before mentioned are complied with, and the work completed to the satisfac-

tion of the and accepted by , whereupon the will pay in cash, on the expiration of days from the time of acceptance, the whole of the moneys accruing to the contractor under these specifications, excepting such sum or sums of money as may be retained under any of the provisions herein contained, and such sums as may have been paid in the form of partial payments upon the monthly estimates of the engineer.

FORMS OF SPECIFICATIONS.

The following forms of specifications may be of assistance in preparing specifications for different works.

1016. Specifications for the Construction of a Highway from to in the town of , county of .

The following specifications are intended to cover the methods of construction and the furnishing of all the labor and materials necessary for the proper and workmanlike completion of the above-named highways in accordance with the plans on file in the office of the engineer, and in accordance with such instructions relating thereto as may from time to time be given by said engineer, or his assistants and inspectors.

Description of the Work.—The character and approximate amounts of work to be done are as follows:

Earth excavation	cubic yards
Loose rock excavation	" "
Solid " "	" "
Embankment to be furnished from	" "
Borrow-pits	" "
Blind stone drains	lineal feet
Tile drains, 3 inches in diameter	" "
" " 6 " " "	" "
Earthenware pipe-culverts, 12" diameter	" "
" " " 18" "	" "
" " " 24" "	" "
Dry box-culverts	cubic yards
" " " , third-class masonry	" "
Dry retaining-walls	" "
Rip-rap	" "
Catch- and silt-basins, number of	
Paved gutters	lineal feet

[Here insert the clauses suitable for each class of work in the schedule.]

1017. Specifications for Bulkhead (Fig. 138, p. 377).

The bulkhead will be formed as follows:

The piles will be of sound straight-grained spruce or other approved timber; they shall measure not less than 6 inches in diameter at the small end and not less than 12 inches nor more than 15 inches at the large end when cut off. The piles shall have the bark removed, be accurately pointed, and when required the heads shall be properly banded to prevent splitting or brooming while being driven; if found necessary, the points shall also be protected with wrought-iron shoes. The piles will be spaced 6 feet from center to center, and shall be driven with a batter of $1\frac{1}{2}$ inches per foot. They may be driven by the hydraulic "jet" or by an ordinary pile-driver; if by the jet, they shall be loaded with a weight of 2000 pounds. By whichever method driven, they shall reach a total penetration into the soil and sand of not less than 15 feet below low-water mark. Piles injured in driving shall be drawn out and replaced by sound ones at the contractor's expense. Piles found too short shall be drawn out and replaced by longer ones.

Lengthening.—Lengthening by using a follower or blocking will not be allowed. Any pile found too short must be drawn out and a longer one substituted. When the piles shall have reached the required depth, their tops shall be sawed off evenly at the established grade.

Pile-cap.—And thereon a pile-cap of yellow-pine timber ten (10) by twelve (12) inches will be laid, fastened to each pile with one one- (1-) inch drift-bolt eighteen (18) inches long. On the water face and thirty (30) inches below the top of the pile-cap there will be placed a

Brace Stick of yellow-pine timber five (5) by ten (10) inches, bolted to every second pile with one one- (1-) inch bolt eighteen (18) inches long. On the water face at mean high-water mark there will be placed a

Chafing-stick of yellow-pine timber five (5) by ten (10) inches, bolted to every pile with one one- (1-) inch bolt. On the land side of the piles at both mean high- and low-water marks there will be placed longitudinally

Wale-sticks of yellow-pine timber five (5) by ten (10) inches, bolted to every pile with one one- (1-) inch bolt.

Sheet-piling.—On the land side of the wale-sticks sheet-piling

of tongued and grooved yellow-pine plank, three (3) inches thick and not less than eight (8) inches wide, will be driven to a depth of not less than ten (10) feet below low-water mark. Each plank will be spiked to both wale-sticks with two six- (6-) inch cut spikes; the tops will be sawed off level with the upper wale-stick.

Anchor-piles.—On the land side and opposite every third pile and eighteen (18) feet distant therefrom an anchor-pile not less than six (6) inches in diameter and ten (10) feet long will be driven to the angle shown on plan, to a penetration of not less than seven (7) feet. At the back of the anchor-piles there will be placed loosely upon the ground a brace-stick of yellow-pine timber five (5) inches by ten (10) inches.

Tension-rods.—Tension-rods made from one and one quarter ($1\frac{1}{4}$) inch iron will extend from front to rear brace-stick, passing through both sticks and piles; the rods will be screwed on both ends and will have under each nut on the water face an iron washer four (4) inches in diameter, cast to the required angle.

Bolt-holes.—All bolt-holes will be bored with an augur one eigth ($\frac{1}{8}$) of an inch smaller than the diameter of the bolt they are to receive.

Fender-piles.—Fender-piles eighteen (18) inches in diameter at the butt and 30 feet long will be driven at every twenty (20) feet along the water face.

Lengths of Timber.—The pile-cap, braces, and chafing-sticks shall be in lengths of not less than eighteen (18) feet; they shall be arranged so as to bring the

Joints on a pile. All joints shall be made by a twelve (12) inch half-lap splice fastened with two seven eighths ($\frac{7}{8}$) inch by fifteen (15) inch bolts. All bolt-heads in pile-cap will be countersunk flush with the top. Iron washers will be placed under all bolt-heads and nuts.

1018. Specifications for Grading, Macadamizing, Curbing, and Flagging Avenue, from to .

Grading.—The entire width of the avenue is to be regulated and graded to sub-grade, fifteen (15) inches below finished grade, in accordance with the grades and cross-section shown in plans. Such portions as are above the grade lines shall be excavated, and such as are below shall be filled in.

Slopes.—Slopes in both embankment and excavation shall be

one and one half ($1\frac{1}{2}$) horizontal to one (1) vertical unless otherwise ordered.

If the material taken from the excavations is unsuitable or insufficient to make the embankments, the deficiency shall be supplied by the contractor. The material so furnished shall be good clean earth, sand, gravel, or broken rock and earth. If broken rock is furnished, the proportion of earth and rock shall not be less than 1 to 1, and the materials shall be so distributed that no voids shall be left.

Any perishable matter that may be found at sub-grade level shall be removed and the space filled in with good material.

The sub-grade surface shall be truly shaped and trimmed to the required cross-section, then rolled with a roller weighing not less than 300 pounds per inch of run. The rolling will be continued until the surface has become firm and hard: in no case shall it be less than 5 hours per 1000 square yards. Such parts as cannot be reached by the roller shall be tamped with hand rammers. Water shall be applied by sprinkling in advance of the roller, but an excess must not be used; generally 25 gallons per 1000 square yards will be sufficient.

On the sub-grade surface prepared as above described a layer of bank gravel will be spread to a depth of nine inches and rolled continuously until the depth is reduced to seven inches; on the foundation so prepared the broken stone will be placed. Its finished thickness will be eight inches. The stones will be spread in two layers: the first layer will be spread to a depth of five and a half inches and rolled till the depth is reduced to five inches; water will be applied in advance of the roller, but not in excess. When the broken stone is so compacted a layer one inch thick of clean sand, or sand containing not more than 15 per cent of loam, will be spread over the surface, and the rolling continued until the stones cease to sink or creep in front of the roller, and the thickness of the layer of broken stone is 4 inches or thereabouts. When the first layer has been finished to the satisfaction of the engineer, the second layer will be spread to the same depth and treated in the same manner as the first layer. The rolling of this surface will be continued until all settlement has ceased.

In quality the stone must conform to the sample in the office of the engineer.

In form it shall be as nearly cubical as practicable, and in size shall not exceed in any dimension two and a half inches, but may range from this size down to quarter-inch chips; but the proportion of stones below one and a half inches shall not exceed 20 per cent of the whole quantity. The stone will not be screened, but shall be delivered as it comes from the breakers; care, however, being taken that clay does not become intermixed with the stone.

Gutters.—For a width of two feet on each side of the carriage-way adjoining the curb a gutter of granite blocks will be laid. Each block shall measure not less than six nor more than nine inches in length, in width not less than three nor more than five inches in depth, not less than seven nor more than eight inches; the blocks to be split and dressed so as to form, when laid, close joints on sides and ends.

The blocks will be laid in courses parallel to the curb. Each course shall be formed with blocks of a uniform width and depth, and laid so that all the longitudinal joints shall be broken by a lap of at least two inches.

The blocks will be laid on the gravel foundation and set stone to stone, both on sides and ends. When thus laid, their surface shall be covered with a layer of clean sharp sand, which shall be swept with brooms until all the joints are filled. Into the sand joints thus made there will be poured a hot mixture of coal pitch and creosote. The whole surface of the blocks will then be covered with one half-inch of sharp sand, which shall be left undisturbed until ordered removed by the engineer.

Curbing.—The curbstones shall be of bluestone, equal in quality to the best North River bluestone. The curbstones shall be not less than three feet in length, five inches thick, twenty inches deep, and matched width throughout. The top of the stone shall be cut to a bevel of one inch; the front shall be cut smooth and to a fair line, to a depth of fourteen inches. The ends from top to bottom shall be truly squared, so as to form close and even joints, and the front so laid as to present a fair and unbroken line. Curbstones shall be back filled, and backed up with at least one foot of clean, gritty earth, free from clay and loam.

Circular Corners.—The curbstones at the corners of intersecting streets shall be cut on a curve, with true and even joints, and

shall be of the same description as the curb before described, and be laid in the same manner.

Flagging.—All the flagging to be of bluestone equal in quality to the best North River bluestone, even on its face, and to measure not less than two feet wide, to contain not less than eight superficial feet, and to be in no place less than three inches thick. To be laid with close joints, in regular courses of four feet wide. Each stone shall be chisel-dressed on the four edges a distance of one inch down from the top and square with the face thereof, and free from drill-holes.

Flagging shall be bedded in four inches of clean, gritty earth or steam ashes, free from clay and loam, and the work brought to an even surface; the joints of the flagging shall be closed up with cement mortar, and be left clean on the surface; the whole space of the sidewalks to be regulated before laying the flagging.

Catch-basins.—Catch-basins will be constructed at the points indicated on the plans or wherever the engineer may direct.

They will be of brick masonry, built with care, of the form and dimensions shown on the plan. They will be made perfectly water-tight by plastering the interior with neat Portland-cement mortar one half-inch thick. The exterior shall be coated with cement mortar one inch in thickness. Each basin will be connected by a nine-inch cement or earthenware pipe-shoot connected to a twelve-inch cement or earthenware pipe. This pipe will be laid on the lines and grades given by the engineer, and connected to the sewer or other outlet.

Each basin will be fitted and furnished with a cast-iron head and grating of the form and dimensions shown on plan.

(*Here insert such clauses for general specifications and stipulations as are suitable.*)

1019. Specifications for the Supply of Broken Stone.—The stone shall be fully equal to the sample in the engineer's office, otherwise it will be rejected.

It shall be broken in as nearly cubical form as practicable, each cube to have a square face and sharp edges, and shall not exceed in any dimension two inches, but the stones may range from this size down to quarter-inch chips; but the proportion of stones below one and a half inches shall not exceed 20 per cent of the whole quantity.

The broken stones shall not be screened, but will be delivered as

they come from the breakers; care, however, being taken that clay does not become intermixed with them.

The stone when delivered must be clean and free from clay or other dirt.

The stone shall be supplied on the order of the engineer in such quantities as he may specify, and must be delivered within the time specified in the order. Failure to so deliver the stone without good and sufficient reason will be a valid excuse for the forfeiture of the contract.

ADDITIONAL CLAUSES REQUIRED IN SPECIFICATIONS FOR REPAIRING, ETC.

1020. Indemnification for Patent Claims.—The contractor shall indemnify and save harmless the   against and from all suits and actions of every nature and description arising out of the claim or claims of any person or persons claiming to be patentees of any process connected with the work herein provided for, or of any materials used upon said work.

1021. Indemnity Bond.—The contractor shall execute with two sufficient sureties a bond in the sum of   thousand dollars, for the indemnification of the   against and from all such suits and actions aforesaid.

1022. Right to Construct Sewers, etc.—The right to construct sewers or any work in connection therewith, lay water, gas, or other mains and make house connections therewith, in advance of the pavement, is expressly reserved by the   ; and the said   may suspend the work on the pavement on any part of the line for the purpose above stated, without other compensation to the contractor for such suspension than extending the time for completing the work as much as it may, in the opinion of the engineer, have been delayed by such suspension. And the contractor shall not interfere with or place any impediment in the way of any person or persons who may be engaged in the construction of such works.

1023. Old Materials.—All old materials which it may become necessary to remove, and where no instructions for their disposal is previously given, shall be considered as the property of the contractor, and the same shall be immediately removed by him from the line of the work.

1024. Security retained for Repairs.—The shall retain out of the moneys payable to the contractor on completion of the work the sum of ten cents per square yard of pavement laid under these specifications, which sum of ten cents with interest shall be paid upon the expiration of the guaranty period; provided that the work at that time is in good order, or as soon thereafter as the work shall have been placed in good order, to the satisfaction of the engineer.

During the guaranty period should any part of the work require repairs, the engineer shall notify the contractor to make such repairs, and in case of neglect or failure to make said repairs within forty-eight hours after service of notice the shall have the right to purchase such materials as may be deemed necessary, and to employ such persons as may be deemed proper, and to undertake and complete such repairs, and to pay the expense thereof out of the said sum of ten cents per square yard retained for that purpose, and such part of said sum as shall remain after the expenses of said repairs have been deducted will be paid in the manner hereinbefore described.

1025. Alteration of Manhole Covers, Stopcock Boxes, etc.—All the frames and heads of sewer manholes, stopcock boxes for water and gas, are to be adjusted (either raised or lowered) to the level of the pavement.

1026. Heads of Specifications for Repaving.

Specifications for Regulating and Paving with Pavement the Carriageway of street / avenue from to

(1) Description of the work.
(2) Removal of old materials.
(3) Excavation.
(4) Adjustment of manhole heads, etc.
(5) Adjustment of curb.
(6) Adjustment of bridge stone.
(7) Furnishing new curb.
(8) Furnishing new bridge stones.
(9) Preparation of roadbed.
(10) Foundation, character of.
(11) Concrete.
(12) Concrete, manufacture and laying.

(13) Pavement, character and quality.
(14) Manner of laying.
(15) Cleaning up.
(16) Quality of material.
(17) Inspectors.
(18) Right to construct sewers.
(19) Commencement of work.
(20) Time of completion.
(21) Suspension of work.
(22) Extension of time.
(23) Damages for non-completion.
(24) Personal attention of contractor.
(25) Contractor's representatives.
(26) Defective work.
(27) Improper prosecution of the work.
(28) Accidents or damages to persons or property to be paid for by the contractor.
(29) Incompetent workmen.
(30) Power to annul contract for violation of stipulations.
(31) Payment of claims for labor and materials.
(32) Measurements.
(33) Engineer's estimates.
(34) Payments, when made.
(35) Percentage retained.
(36) Prices.
(37) Interpretation of specifications.
(38) Engineer defined.
(39) Contractor defined.
(40) Preservation of engineer marks, etc.
(41) Indemnification of patent claims.
(42) Indemnity bond.
(43) Security retained for repairs.

1027. Specifications for Street cleaning should Contain the following Conditions.—The mode of cleaning shall be to first clean the gutters of all solid matter, and then sweep from the sides towards the centre; dirt collections not to be placed within 5 feet of the gutters.

Whenever the sweeping of streets would cause the dust to rise, they shall be first sprinkled by sprinkling-wagons to be approved

by the of the of ; and the sprinkling shall be so done that the dust will not be turned into mud.

All hand sweeping shall be done with push-brooms, and all sweeping by machinery with machines approved by the of .

All parts of streets covered with sheet asphalt shall be swept by machinery six times each week, between the hours of 10 P.M. and 6 A.M., and a sufficient number of men with bass brooms shall be kept employed to keep them constantly clean between the hours of 7 A.M. and 6 P.M.

All accumulations of sweepings, and of mud or rubbish removed from inlets or gutters, shall be removed within three hours from the time such heaps are made, in carts tightly built in such a manner that the contents can be removed without spilling or leaking, and the place where they had been collected shall be swept clean.

All gutters kept wet by the flow of filthy water or sewage shall be thoroughly scraped, brushed, and flushed at least twice a week from May 1st to November 1st, and for this work each contractor will be required to keep at least 100 feet of hose in each district, and brushes or brooms especially made for work of this kind shall be used in cleaning the gutters.

All solid matter must be removed from the gutters and inlets before they are flushed.

All street crossings, inlets, gutters approaching the same, and all gutters necessary to drain crossings within 100 feet of inlets, and streets in front of fire-plugs, for a radius of 5 feet, must be kept clean of dirt, mud, ice, and snow.

1028. Instructions to Bidders.—*Proposals for* [insert description and location of the work]. In pursuance of the following ordinance [insert ordinance].

Sealed proposals for the above work, indorsed with the above title, also with the names of the person or persons making the same and the date of presentation, will be received at the office of until o'clock .M., day of , 189 , at which place and hour the bids will be publicly opened by and read, and the award of the contract will be made to the lowest responsible bidder with adequate security as soon thereafter as practicable. The person or persons to whom the contract may be awarded will be required to attend at the office of with the sureties offered by him or them, and execute the contract within

five days from the date of the service of a notice to the effect that the contract has been so awarded, and that the adequacy and sufficiency of the security offered has been approved by the ; in case of failure or neglect so to do, he or they will be considered as having abandoned it, and as in default to the ; and thereupon the work will be readvertised and relet, and so on until the contract be accepted and executed. The work is to be commenced at such time as the engineer may designate.

The price must be written in the bid, and also stated in figures, and all proposals will be considered as informal which do not contain bids for all the items for which prices are herein called for, or which contain prices for items not called for, or which contain erasures, alterations, or other irregularities.

Permission will not be given for the withdrawal of any bid or estimate, and the right is expressly reserved by the to reject all bids if it shall be deemed for the public interest so to do. No bid will be accepted from or contract awarded to any person who is in arrears to the upon debt or contract, or who is a defaulter, as surety or otherwise, upon any obligations to the .

Bidders are required to state in their estimates, under oath, their names and places of residence, the names of all persons interested with them therein, and if no other person be so interested, they shall distinctly state the fact; also that it is made without any connection with any other person making a bid or estimate for the same work, and that it is in all respects fair and without collusion or fraud; and also that no member of or other officer of the is directly or indirectly interested therein, or in the supplies or work to which it relates, or in any portion of the profits thereof. Where more than one person is interested, it is requisite that the verification be made and subscribed by all the parties interested.

Each estimate shall be accompanied by the consent, in writing, of two householders or freeholders in the , with their respective places of residence, to the effect that if the contract be awarded to the person making the estimate, they will, upon its being so awarded, become bound as his sureties for its faithful performance; and that if he shall omit or refuse to execute the same, they will pay to the any difference between the sum to which he would be entitled upon its completion, and that which the said

may be obliged to pay to the person to whom the contract shall be awarded at any subsequent letting; the amount in each case to be calculated upon the estimated amount of the work by which the bids are tested. The consent above mentioned shall be accompanied by the oath or affirmation, in writing, of each of the persons signing the same, that he is a householder or freeholder in the and is worth the amount of the security required for the completion of the contract and stated in the proposals, over and above all his debts of every nature and over and above his liabilities as bail, surety, and otherwise, and that he has offered himself as surety in good faith and with an intention to execute the bond required by law. The adequacy and sufficiency of the security offered will be determined by the of the

In case a proposal is submitted by or in behalf of any corporation it must be signed in the name of such corporation by some duly authorized officer or agent thereof, who shall also subscribe his own name and office. If practicable, the seal of the corporation should also be affixed.

The successful bidder will be strictly held to the time bid for completion of the work, and to the conditions of the specifications.

The engineer's estimate of the nature and extent of the work to be done and materials to be furnished is as follows: [Insert estimate.]

As the above quantities, though stated with as much accuracy as is possible in advance, are approximate only, bidders are required to submit their estimate upon the following express conditions, which shall apply to and become part of every estimate received:

1. The items and quantities stated in the above schedule are merely approximate and may be altered in part or wholly changed during the progress of the work. They are intended only to indicate the general character of the work and shall not be made a basis of any claim for extra compensation of profits in case the quantities of the final estimate shall vary from them, nor be regarded as having any relation or bearing whatever upon the quantities of the final estimate.

2. Bidders must satisfy themselves by personal examination of the site of the proposed work as to the difficulties to be encountered and such other matters which can in any way influence their estimates, and no information derived from the drawings or specifica-

tions or from the engineer or any of his assistants will relieve the contractor from any risks or from fulfilling the terms of the specifications and contract.

3. The contractor will be required to complete the entire work to the satisfaction of the and in substantial accordance with the specifications.

No estimate will be received or considered unless accompanied by either a certified check upon one of the National or State banks of the drawn to the order of the , or money to the amount of five per centum of the amount of the security required for the faithful performance of the contract. Such check or money must not be inclosed in the sealed envelope containing the estimate, but must be handed to the officer or clerk of the department who has charge of the estimate box, and no estimate can be deposited in said box until such check or money has been examined by said officer or clerk and found to be correct. All such deposits, except that of the successful bidder, will be returned to the persons making the same within three days after the contract is awarded. If the successful bidder shall refuse or neglect, within five days after notice that the contract has been awarded to him, to execute the same, the amount of the deposit made by him shall be forfeited to and retained by the as liquidated damages for such neglect or refusal; but if he shall execute the contract within the time aforesaid, the amount of his deposit will be returned to him.

Bidders are particularly cautioned that in no case will they be permitted to use materials either in quantity or quality different from those described in the specifications. [And also, that a provision in the specifications and contract requires the maintenance of the pavement in good condition for the period of from the final completion and acceptance thereof.]

The amount of security is thousand dollars for the faithful performance of the contract, and also for the indemnification of the for infringement of patents the amount is thousand dollars. The contractor must notify the engineer in writing hours before commencing the work. The plans can be seen and blank forms of proposals and further information can be obtained on application at the office of

1029. Form of Proposal.

NO. BID OR ESTIMATE.

For [insert description of work] , made by , residing at , and residing at , and residing at , and residing at , composing the firm of .

1. declare that the only person interested in this proposal; and no other person other than herein above named ha any interest in this proposal, or in the contract proposed to be taken.

2. further declare that this proposal is made without connection with any other person or persons making a proposal for the same purpose, and is in all respects fair, and without collusion or fraud.

3. further declares that no member of the or other officer is directly or indirectly interested in this proposal, or in the supplies or work to which it relates, or in any portion of the profits thereof.

4. further declares that the names of the persons affixed to the consent hereto annexed were written by said persons respectively, and that said persons are householders or freeholders in the .

5. have examined the proposals for estimates for the above work, dated the day of , 189 , and published in the , and the form of contract for the work (including the plans and specifications for the work), and have also visited and examined the site and location and made the investigations recommended in the instructions to bidders, and will contract to furnish the material and perform and complete the work mentioned in said proposals for estimates and approved form of contract on the following terms, viz.: For clearing, grubbing and close cutting, per acre, the sum of . For earth excavations for all classes, per cubic yard, the sum of . For loose rock excavation, per cubic yard, the sum of . For solid rock excavation, per cubic yard, the sum of . For 12-inch culvert pipe, per linear foot, the sum of . For 24-inch culvert pipe, per linear foot, the sum of . For concrete, per cubic yard, the sum of . For each receiving basin, complete, with iron head and grating, the sum of

For brick masonry, per cubic yard, the sum of .

For yellow-pine timber, including fastenings, per 1000 feet-board measure, the sum of For spruce and other plank, including fastenings, per 1000 feet board measure, the sum of . For riprap, per cubic yard, the sum of . For dry stone masonry, per cubic yard, the sum of .

The above prices include the furnishing of all the materials, tools, plant, and labor, and every risk and contingency necessary for the completion of the work in accordance and with specifications and plans.

Time within which will complete the whole work according to specifications days.

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CITY OF , COUNTY OF , *ss.:*

....

being duly sworn, say, each for himself, that the several matters stated in the above estimate are in all respects true.

Subscribed and sworn to this day of , A.D. 189 , before me,

....

Commissioner of Deeds.

1030. Form of Agreement (to be executed in triplicate).

This agreement made and entered into this day of , one thousand eight hundred and , by and between the [insert name of city, town, or county] of , hereinafter called the party of the first part, and [name of contractor], of the [insert place of residence], hereinafter called the party of the second part,

Witnesseth: That the said party of the second part has agreed, and by these presents does for himself, his heirs, executors, administrators, and assigns, covenant, promise, and agree with the said parties of the first part, for the considerations hereinafter mentioned

and contained, and under the penalty expressed in a bond bearing even date with these presents, and hereunto annexed, that he, the said party of the second part, his heirs, executors, administrators, or assigns, shall and will furnish and provide, at his own or their own cost and expense, all the necessary materials, appliances, tools, plant, and labor which are or may be necessary for the proper and substantial construction and completion of the [insert description of work], in accordance with the general plans on file in the office of the said party of the first part, and in strict conformity in every part and particular with the following specifications, and in accordance with such detail plans and instructions relating thereto as may from time to time be given by the chief engineer or his duly appointed assistants; and further agrees that the said parties of the first part shall be, and are hereby, authorized by their chief engineer, or such other person or persons, or in such other manner, as they may deem proper, to inspect the material to be furnished and the work to be done under this agreement, and to see that the same correspond with the specifications and conditions hereinafter set forth.

The party of the second part admits and agrees that the amounts and quantities of materials to be furnished and work to be done, as stated in the proposals for estimates for the said work, are approximate only; that he is satisfied with the foregoing estimate in determining the price according to which he agrees to do the work required by this contract in accordance therewith, and that he shall not and will not dispute or complain of such statement, nor assert that there was any misunderstanding in regard to the nature or amount of the materials to be furnished or work to be done; and he covenants and agrees that he will complete the entire work to the satisfaction of the and in substantial accordance with said specifications and the plan therein mentioned, and that he will not ask, demand, sue for, or recover for the entire work any extra compensation beyond the amount payable for the several classes of work in this contract enumerated, which shall be actually performed, at the price therefor herein agreed upon and fixed.

The parties hereto also declare that this contract is made with reference to the proposals for estimates for the above-described work, hereto annexed, and the estimate of the contractor now on file

in the , which are to be taken as part and parcel of these presents [here insert specifications and general stipulations].

Commencement.—The said party of the second part hereby further agrees to commence the work comprised under this agreement on such day and at such place or places as the engineer may designate. Failure to so commence will be authority for the party of the first part to declare this agreement forfeited, and the said party of the first part may proceed with the execution of the work in such manner as they may deem proper.

Time of Completion.—The party of the second part agrees to prosecute the work in such manner as to complete the same in accordance with this agreement on or before the expiration of two hundred (200) days after the date of commencement, and it is further agreed that in the computation of said time, the length of time (expressed in days and parts of a day) during which the work or any part thereof has been delayed in consequence of the condition of the weather, or by any difficult circumstances so unusual that they could not be foreseen previous to, or avoided during, the construction of the work, or by any act or omission of the parties of the first part (all of which shall be determined by the chief engineer, who shall certify to the same in writing), and also Sundays and holidays on which no work is done, and days on which the prosecution of the work is suspended by order of the party of the first part, shall be excluded.

But if the construction of said work should require material or work in greater or lesser quantities or amounts than those mentioned and set forth in the engineer's estimate, then the said time shall be increased or diminished as much as the said engineer, by a certificate in writing, shall deem just and reasonable, and fairly proportioned to the amount of said increase or diminution.

But neither an extension of time for any reason beyond the date fixed herein for the completion of the work, nor the doing and acceptance of any part of the work called for by this agreement, subsequent to the said date, shall be deemed to be a waiver by the said party of the first part of the right to abrogate this contract for abandonment or delay in the manner provided for in Article 80 of this agreement.

Damages for Non-completion.—And the said party of the second part hereby further agrees, that the said parties of the first part

shall be and are hereby authorized to deduct and retain out of the moneys which may be due or become due to the said party of the second part under this agreement, as damages for the non-completion of the work aforesaid within the time hereinbefore stipulated for its completion, the sum of dollars for each and every day which may exceed the said stipulated time for its completion; which said sum of dollars per day is hereby, in view of the difficulty of estimating such damages agreed upon, fixed and determined by the parties hereto as the liquidated damages that the parties of the first part will suffer by reason of such default, and not by way of penalty.

Improper Prosecution of Work.—The said party of the second part further agrees that if at any time it should appear to the engineer that the works are being delayed, or are not being prosecuted with due diligence, or with such speed as would be necessary for their completion within the time specified, or that the works are being prosecuted in an improper or unworkmanlike manner, the said engineer shall notify the contractor in writing, specifying the causes of complaint, and upon the party of the second part failing to rectify such matters within seven days after the receipt of said notice, the engineer shall notify the party of the first part of such failure; and it is further agreed, that in the event of such failure the party of the first part may, without further notice, suspend the contractor from all work under this agreement; and it is further agreed, that the said party of the second part shall immediately respect said suspension, and shall stop work, and cease to have any rights to possession of the ground; and the said party of the first part shall thereupon have the power to carry on and complete the work herein described, by contract or otherwise, employing such plant, tools, and materials as may be on the ground, and procuring such others as may be wanting, for the proper completion of the work, and to charge the expense of such labor and materials to the aforesaid party of the second part, and the expense so charged shall be deducted and paid out of such moneys as may be then due, or may at any time thereafter become due, to the said party of the second part under or by virtue of this agreement, or any part thereof; any excess of cost over and above the amount accruing as above stated shall be charged against the party of the second part and his sureties, who will each and severally be held liable there-

for; and in case the cost of completion shall be less than the sum which would have been payable under this contract if the same had been completed by the party of the second part, he shall be entitled to receive the difference.

Engineer's Returns.—The said party of the second part further agrees that the return of the engineer shall be the account by which the amount of material furnished and work done in terms of this contract shall be computed; provided, however, that nothing herein contained be construed to affect the right of the party of the first part to reject and contest any return or certificate of the engineer or inspectors having charge of the work, should such return or certificate be in their opinion not in accordance with the facts of the case or the requirements of this agreement, or otherwise improperly given.

Damage to Property.—And it is hereby further agreed, that in case any damage or injury shall or may result to buildings, water-pipes, hydrants, gate-boxes, sewer-basins, man-holes, sewers, or other works through or by reason of any negligence, carelessness, or want of skill on part of said party of the second part, the said party of the second part shall restore the same to their former good condition; failing to do so, said party of the second part shall pay such amount as shall or may be sufficient to cover the expense and damage occasioned by such negligence, carelessness, or unskilfulness.

Gas-pipes.—And the said party of the second part further agrees to do everything necessary to support and sustain the gas-pipes laid in or across said streets, which may be liable to any injury from digging the trenches for the work hereinbefore mentioned, and to have a sufficient quantity of timber and plank constantly on the ground, and to use the same as required for bracing and sheet-piling the sides of the excavation.

Notice to Gas Companies.—And the said party of the second part further agrees to give notice in writing, at least twenty-four hours before breaking ground for the purpose of constructing the work hereinbefore mentioned, to such and all such gas companies as have, or may during the progress of the work have, any gas-pipes which may be affected by such excavations as may become necessary.

And it is further agreed, that the said party of the second part

shall not cause any hindrance to or interfere with such gas company or companies in protecting their pipes, nor in removing or otherwise protecting and replacing the main and service pipes, lamp-posts and lamps, where necessary; but that the said party of the second part will suffer the said company or companies to take all such measures as may become necessary for the purpose aforesaid.

Penalty of Damage to Gas-pipes.—And it is hereby further agreed, that in case any damage or injury shall or may result to the said pipes, lamp-posts, lamps, or other works of any gas company, through or by reason of any negligence, carelessness, or want of skill on the part of the said party of the second part, his agents or servants, the said party of the second part shall become liable to pay such amount as shall or may be sufficient to cover the expense and damage occasioned by such negligence, carelessness, or unskilfulness; and such amount shall be charged against the said party of the second part, and may be deducted from any sum or sums due or to become due or payable to said party of the second part on account of this contract.

Water-pipes.—The party of the second part hereby further agrees to sustain in their places, without injury, all the main and service water-pipes which may be affected in any manner by the work under this agreement, including any such protective measures as may be required in cold weather to prevent them from freezing; or failing to do so, the said shall be and he is hereby authorized to replace and recalk and repair the same immediately in each block, as the work progresses, and the cost thereof shall be charged to the said party of the second part, and the cost so charged to the said party of the second part shall be retained and deducted, and the parties of the first part are hereby authorized to retain and deduct said cost out of the moneys which may be due or become due to the said party of the second part under this agreement.

Transfer of Contract.—The party of the second part further agrees not to transfer or sublet any part of the work referred to in this agreement, without the previous written consent of the engineer; any such transfer or subletting without said consent will be null and void, and will be sufficient cause for the annulment of

the contract; nor shall any of the moneys payable under this contract be assigned by power of attorney or otherwise.

Loss or Damage.—And it is further agreed that all loss or damage arising out of the nature of the work to be done, or from any unforeseen or unusual obstructions or difficulties which may be encountered in the prosecution of the same, or from the action of the elements, or from injury to persons or property of another, resulting from negligence in the performance and guarding of the same, which must be protected when necessary with barriers, and at night with red lights, or from any improper materials used in prosecution or by or on account of any act or omission of his own, or his agents, will be sustained by the contractor, and he shall save harmless the party of the first part from any and all liabilities and claims for such, and the said party of the first part shall have the right to retain any moneys that may be due or become due, until evidence has been furnished that all such suits or claims for damages as aforesaid have been satisfactorily settled.

Public Protection.—It is further agreed that the contractor will enclose every opening he may make in the public highway with sufficient barriers, and must maintain red lights at the same at night, and must take all necessary precautions to guard effectually against accidents to persons, horses, vehicles, or property of any kind, and all work shall be done in such manner and at such times as to interfere as little as possible with public travel and convenience; and the contractor shall conduct his work for this object as the engineer may from time to time direct.

Work not Provided for in Contract.—The said party of the second part further agrees, that if, before the completion of the work contemplated herein, it shall become necessary to do any other or further work on or about this regulating, etc., than is provided for in this contract, or to construct any sewer or sewers or appurtenances thereof, on the line of this work, the said party of the second part will not in any way interfere with or molest such other person or persons as the   may employ to do such work, and will suspend each part of the work herein specified, or will carry on the same in such manner as may be ordered by the said   , to afford all reasonable facilities for doing such work, and no other damage or claim by the said party of the second part hereof shall be allowed except such extension of the time specified

in this contract for the performance thereof as the may deem reasonable.

Security to be retained for Repairs.—And the said party of the second part hereby further agrees that the said parties of the first part shall be and are hereby authorized to retain, out of the moneys payable to him under this agreement, the certain sum of twenty-five cents per linear foot of the work done under this agreement, and to expend the same, in the manner provided for, in making such repairs to the work done under this agreement as the said may deem necessary, except curbing and flagging, which will be finally accepted upon the completion of the work. And it is further agreed that if, at any time during the period of six months from the date of the acceptance by said of the work under this agreement, the said work or any part thereof (excepting only such part or parts of the work as after the completion thereof may have been disturbed in the construction or repairs of sewers or drains, or in laying or repairing gas or water main or service pipes, or railroad-pier foundations) shall in the opinion of the said require repairs, the said shall notify the said party of the second part to make the repairs so required, the said party of the second part shall immediately commence and complete the same to the satisfaction of said ; and in case of failure or neglect, on his part, to do so within forty-eight hours from the date of the service of the aforesaid notice, then the said shall have the right to purchase such materials as he shall deem necessary, and to employ such person or persons as he may deem proper, and to undertake and complete the said repairs, and to pay the expense thereof out of the said certain sum retained for that purpose by the said parties of the first part, as before mentioned. And the parties of the first part hereby agree, upon the expiration of the said period of six months, provided that the said work at that time be in good order, or as soon thereafter as the said work shall have been put in good order to the satisfaction of the said , to pay to the said party of the second part the whole of the sum last aforesaid or such part thereof as may remain after the expense of making such repairs, in the manner aforesaid, shall have been paid therefrom. And it is hereby further agreed, between the parties hereto, that if the termination of the said period of six months after the completion and acceptance of the work done

under this agreement shall fall within the months of December, January, February, and March, then in that case the said months of December, January, February, and March, or such part thereof as the may determine, shall not be included in the computation of the said period of six months.

Prices.—And the party of the second part hereby further agrees to receive the prices set forth in the following schedule as full compensation for furnishing all materials and labor, and the doing of all work, including all loss or damage arising out of the nature of the work, or from the action of the elements, or from any unforeseen obstructions or difficulties, which may be encountered in the prosecution of the same; also all expenses incurred by or in consequence of the suspension or discontinuance of said work which may be required in building and constructing, and in all respects completing the aforesaid [insert description of work], including all appurtenances and accessories, to the satisfaction of the engineer and the hereinbefore mentioned authorities, and in the manner and under the conditions hereinbefore specified, to wit: [insert schedule of prices].

Manner of Payment.—And the said party of the second part further agrees that he shall not be entitled to demand or receive payment for any of the aforesaid work or material until the same shall be fully completed in the manner set forth in this agreement, and such completion duly certified by the chief engineer, and until each and every one of the stipulations hereinbefore mentioned are complied with.

Whereupon the parties of the first part will pay, and hereby bind themselves and their successors to pay, to the said party of the second part, on account, ninety (90) per cent of the monthly estimate of the whole amount of money accruing to the said party of the second part, and the reserved ten (10) per cent upon the formal acceptance of the work by the party of the first part.

In witness whereof, the ha hereunto set hand and seal on behalf of the said parties of the first part, and the said party of the second part hath also hereunto set hand and seal , the day and year first above written; and said commissioner and party hereto of the second part hath executed this agreement in triplicate, one part of which is to remain with

the said , one other to be filed with the , and the third to be delivered to the said party hereto of the second part.

Signed and sealed in presence of

....

....

Contractor.

STATE OF , CITY OF , COUNTY OF , *ss.:*

On this day of , 189 , before me personally came

to me known, and known to me to be the , the person described in and who executed the foregoing instrument, and he acknowledged to me that he executed the same as such , for the purposes therein mentioned.

....

Commissioner of Deeds,

.... County.

STATE OF , CITY OF , COUNTY OF , *ss.:*

On this day of 189 , before me personally came

to me known, and known to me to be the person described in and who executed the foregoing instrument, and he acknowledged to me that he executed the same for the purposes therein mentioned.

....

Commissioner of Deeds,

.... County.

1031. Form of Bond.

Know all men by these presents, that we,

of the , are held and firmly bound unto the of the in the sum of thousand dollars lawful money of the United States of America, to be paid to the said , or to their certain attorney, successors, or assigns; for which payment, well and truly to be made, we bind ourselves, and our several and respective heirs, executors, and administrators, jointly and severally, firmly by these presents.

Sealed with our seals. Dated this day of , one thousand eight hundred and

Whereas, the above bounden

by an instrument in writing under hand and seal , bearing even date with these presents, ha contracted with the said to furnish all the materials and labor, and in a good, firm, and substantial manner construct [description of work]:

Now, therefore, the condition of the above obligation is such, that if the said above bounden

or executors, administrators, or assigns, shall well and truly, in a good, sufficient, and workmanlike manner, perform the work mentioned in the aforesaid agreement, in accordance with the terms and provisions therein stipulated, and in each and every respect comply with the conditions and covenants therein contained, then this obligation to be void; otherwise to remain in full force and virtue.

....

Signed and sealed in presence of ....

....

....

....

STATE OF , CITY OF , COUNTY OF , *ss.:*

On this day of , 189 , before me personally came

to me personally known, and known to me to be the same persons described in and who executed the foregoing obligation, and severally acknowledged that they executed the same.

....

Commissioner of Deeds,

.... County.

STATE OF , CITY OF , COUNTY OF , *ss.:*

I , of said , being duly sworn, do depose and say, that I am a holder in the of and in

said , and that I am worth the sum of one thousand dollars over and above all my debts and liabilities, including my liabilities as bail, surety, and otherwise, and over and above all my property which is exempt by law from execution.

Subscribed and sworn to this
day of , 189 , before me, } ....

....
Commissioner of Deeds.
.... County.

CHAPTER XXIII.

TOOLS AND MACHINERY EMPLOYED IN THE CONSTRUCTION OF HIGHWAYS.

THE implements employed in the construction of highways and pavements are many and varied. A brief description of the principal ones, with current prices, is given in the following pages. The prices stated are only approximate and will vary, depending upon the quantity required and the condition of the market.

1032. Tools for Clearing and Grubbing.

Axes	price per dozen	$12.00 to	$15.50
Bush-hooks, handled	" " "	17.00	
Grub-hoes	" " "	11.00 to	17.00
Mattocks	" " "	15.50 "	18.00
Stump-pulling machines	each	150.00 "	250.00
Cross-cut saws	per foot	0.68	

1033. Tools for Grading.—*Picks* (Fig. 186) are made with solid

FIG. 186. GRADING-PICK.

wrought-iron eye, pointed with steel; they weigh from 4 to 9 lbs., and cost per dozen from $8.50 to $30.00.

Shovels are made in two forms, square and round pointed, usually of pressed steel. They cost from $7 to $13 per dozen for the square-pointed and from $7.25 to $13.50 for the round-pointed.

Ploughs are extensively employed in grading, special forms being manufactured for the purpose. They are known as "grading-ploughs," "road-ploughs," breaking-ploughs," "township-ploughs,"

etc. They vary in form according to the kind of work they are intended for, viz., loosening earth, gravel, hardpan, and some of the softer rocks.

These ploughs are made of great strength, selected white oak, rock elm, wrought steel and iron being generally used in their construction.

The cost of operating ploughs ranges from 2 to 5 cents per cubic yard, depending upon the compactness of the soil.

The quantity of material loosened will vary from 2 to 5 cubic yards per hour.

Fig. 187 shows the form usually adopted for loosening earth. This plough does not turn the soil, but cuts a furrow about 10

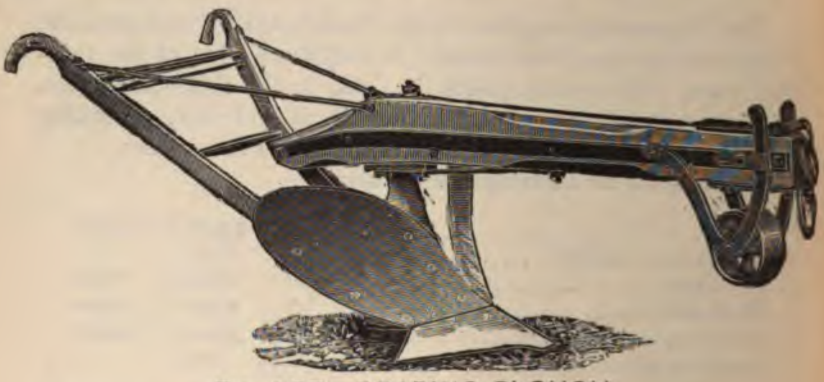


FIG. 187. GRADING-PLOUGH.

inches wide and of such a depth as it may be regulated for from 6 to 11 inches.

In light soils the ploughs are operated by two or four horses, in heavy soils as many as eight are employed.

Grading-ploughs vary in weight from 100 to 325 lbs., in price from $22 to $65.

Scrapers are generally used to move the material loosened by ploughing; they are made of either iron or steel, and in a variety of forms, and are known by various names, as "drag," "buck," "pole," and "wheeled."

The drag-scrapers are usually employed on short hauls, the wheeled on long hauls.

Figs. 188 to 191 illustrate some of the more usual forms.

FIG. 188. DRAG-SCRAPER.

Drag-scrapers are made in three sizes. The smallest, for one horse, has a capacity of 3 cubic feet; the others, for two horses, have a capacity of 5 to 7½ cubic feet. The smallest weighs about 90 lbs., and the larger ones weigh from 94 to 102 lbs.

The price is variable, iron being the cheapest and steel the dearest; the range appears to be from $12 to $18.

A recent improvement in drag-scrapers is the furnishing them with runners or a double bottom. These devices prolong the life of the scraper. Fig. 189 shows a drag-scraper furnished with steel runners.

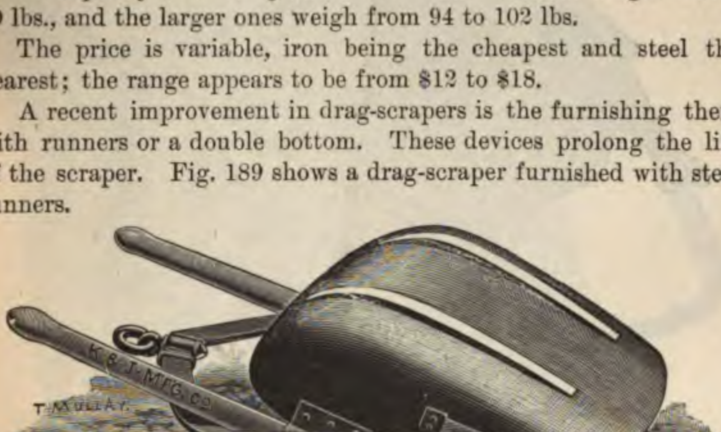


FIG. 189. DRAG-SCRAPER WITH RUNNERS.

Buck-scrapers made in two sizes—two-horse, carrying 7½ cubic feet; four-horse, 12 cubic feet.

Fig. 191. TWO-HORSE BUCK-SCRAPER. READY FOR LOADING.

Pole-scraper, generally used for ditching, is shown in Fig. 191.

FIG. 191. POLE-SCRAPER.

Wheeled Scrapers are made in various sizes, ranging in capacity from 12 to 17 cubic feet. The wheels are about 31 inches in diameter and have a tread of from 3 to 3½ inches. In weight they range from 350 to 450 lbs.; in price, from \$50 to \$75.

Figs. 192 to 194 show the three positions of the scrapers when in use.

FIG. 192. POSITION WHEN LOADING.

Wheelbarrows.—The wheelbarrow Fig. 195 is constructed of wood and is the one most commonly employed for earth-work. Its capacity ranges from 2 to 2½ cubic feet. Weight about 50 lbs. Price about \$20 per dozen.

The barrow Fig. 196 has a pressed-steel tray, oak frame, and

steel wheel, and will be found more durable in the maintenance department than the all-wood barrow. Capacity from 3½ to 5 cubic feet, depending on size of tray. Price from $5.50 to $7.50.

FIG. 193. POSITION WHEN CARRYING.

FIG. 194. POSITION WHEN UNLOADED.

The barrow Fig. 197 is constructed with tubular iron frames and steel tray, and is adaptable to the heaviest work, such as

Fig. 195.

Fig. 196.

Fig. 197.

moving heavy broken stone, etc., or it may be employed with advantage in the cleaning department. Capacity from 3 to 4 cubic feet. Weight from 70 to 82 lbs. Price from $10.75 to $13.50.

Carts.—The cart usually employed for hauling earth, etc., is shown in Fig. 198. The average capacity is 22 cubic feet, and the average weight is 800 lbs. Price about $75.

These carts are usually furnished with broad tires, and the body is so balanced that the load is evenly divided above the axle.

The time required to load a cart varies with the material. One shoveller will require about as follows: clay, seven minutes; loam, six minutes; sand, five minutes.

FIG. 198. EARTH-CART.

Dump-cars.—These cars are made to dump in several different ways, viz., single or double side, single or double end, and rotary or universal dumpers.

Dump-cars may be operated singly or in trains, as the magnitude of the work may demand. They may be moved by horses or small locomotives. They are made in various sizes, depending upon the gauge of the track on which they are run. A common gauge is 20 inches, but varies from that up to the standard railroad gauge of 56½ inches.

The principal dimensions, capacity, prices, etc., of single side

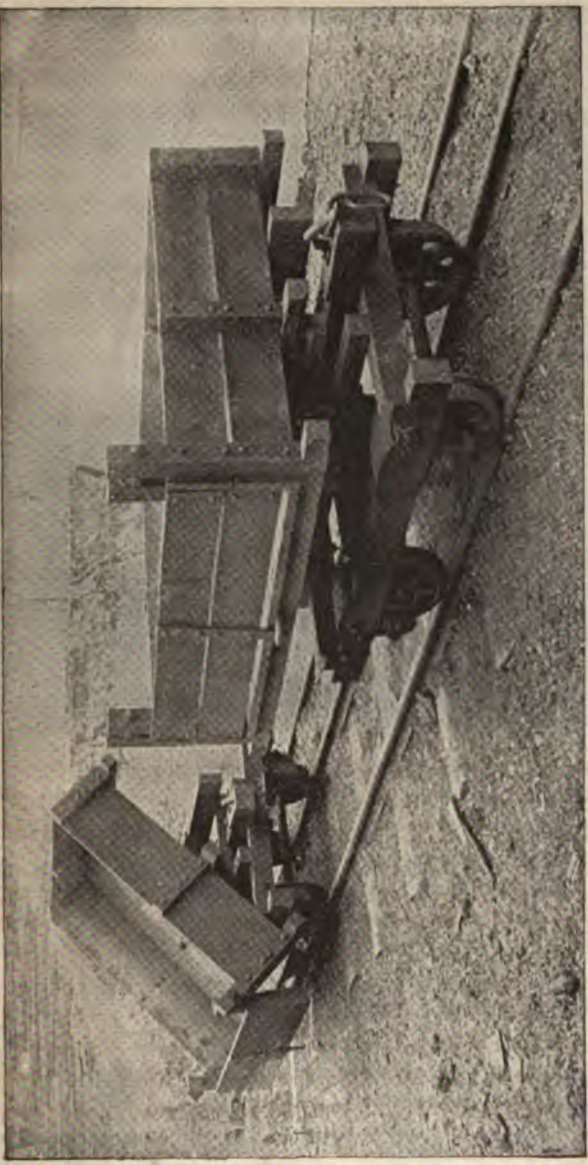


FIG. 199.—SIDE DUMP-CAR.

dumping-cars are given in the following table. Those made by different manufacturers vary, but not materially, from the figures given.

FIG. 200. ROTARY DUMP-CAR.

DIMENSIONS, CAPACITY, PRICES, ETC., OF DUMP-CARS.

Gauge. Inches.	Dimensions. Length over all.	Wheel-base.	Length of Body.	Width.	Depth.	Top of Body above Rail.	Diameter of Wheels.	Diameter of Axles.	Weight.	Capacity, Cubic yards.	Price.
	ft. in.	ft. in.	ft. in.	ft. in.	in.	ft. in.	in.	in.	lbs.		
20	7 5	3 3	5 0	5 0	16	4 0	16	2¼	1300	1¼	$64
30	"	"	"	"	"	"	"	"	1400	"	67
36	"	"	"	"	"	"	"	"	1450	"	70
36 to 56½	8 4	3 5	6 0	6 0	24 to 30	"	20	"	2000	2¼ to 3	100 to 110

Track and Track Fastenings.—The rails used on construction range from 12 to 25 lbs. per yard. The price varies considerably with the condition of the market.

The number of tons of rails required per mile is as follows:

Weight per yard.	Tons of 2240 lbs. per mile.
12 lbs.	18 tons 1920 lbs.
16 "	25 " 320 "
20 "	31 " 960 "
25 "	39 " 640 "
28 "	44 " 000 "

The number of cross-ties per mile is as follows:

Centre to Centre.	No. of Ties.
1½ feet	3.520
1¾ "	3.017
2 "	2.640
2¼ "	2.348
2½ "	2.113

The number of splice-joints per mile is as follows (two bars and four bolts and nuts to each joint):

Rails 20 feet long	528 joints.
" 24 " "	440 "
" 26 " "	406 "
" 28 " "	378 "
" 30 " "	352 "

The size of spikes used and the number required per mile is as follows (four spikes per tie):

Weight of Rail.	Size, measured under head.	Ties, 2 ft. C. to C., require Kegs	Average Number per Keg of 200 lbs.
24 to 35 lbs.	4" × ½"	17⅜	600
20 to 30 "	4 × 7/16	14¾	720
16 to 25 "	4 × ⅜	10½	1000
16 to 20 "	3½ × ⅜	9	1190
16 to 20 "	3 × ⅜	8½	1240
12 to 16 "	2½ × ⅜	7⅞	1342

Dump-wagons (Fig. 201).—Capacity ranges from 35 to 45 cubic feet.

FIG. 201. THE AUSTIN DUMP-WAGON—DUMPED.

Mechanical Graders.—Within the last few years several machines have been devised for the purpose of handling earth more expeditiously and economically than can be done by hand; they are called by various names, such as "road machines," "graders," "road hones," etc. Their general form is shown in Figs. 202 to 204.

Briefly described, they consist of a large blade made entirely of steel or of iron, or wood shod with steel, which is so arranged by mechanism attached to the frame from which it is suspended that it can be adjusted and fixed in any direction by the operator. In their action they combine the work of excavating and transporting the earth. They have been chiefly employed in the forming and maintenance of earth roads, but may be also advantageously used in preparing the subgrade surface of roads for the reception of broken stone or other improved covering.

A large variety of such machines are on the market, and the price ranges from $100 to $300.

Besides the above style of machines there is another known as the "New Era" grader. This machine excavates the material

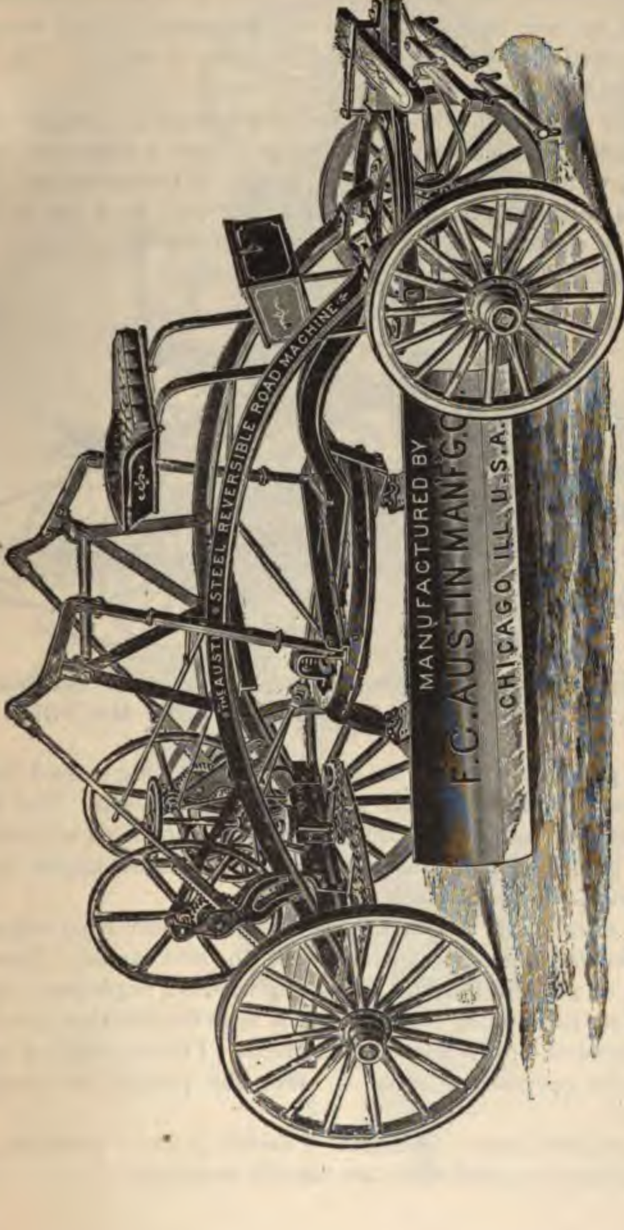


FIG. 202. THE AUSTIN STEEL REVERSIBLE ROAD MACHINE.

from side ditches, and automatically places it in the embankment, or it can be used in a cutting, in which situation it will excavate and automatically load the material into carts or wagons. Fig. 205 shows the machine at work.

Briefly described, the machine consists of a plough which loosens and raises the earth, depositing it upon a transverse carrying-belt, which conveys it from excavation to embankment. This carrier is built in four sections, bolting together, so it can be used to deliver earth at 14, 17, 19, or 22 feet from the plough. The carrier-belt is of heavy 3-ply rubber 3 feet wide.

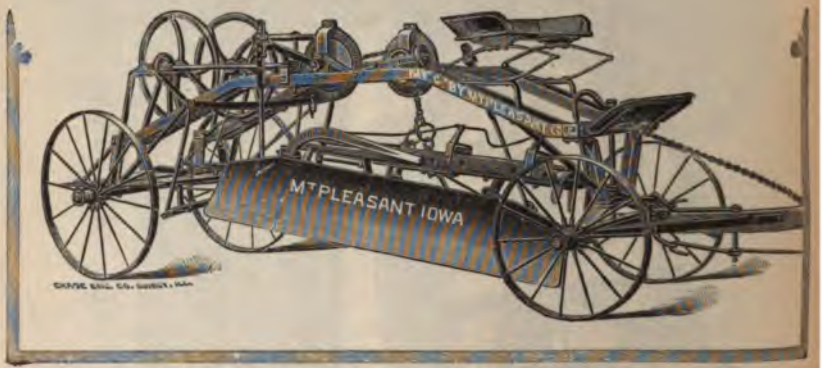


FIG. 203. THE MT. PLEASANT ROAD MACHINE.

The plough and carrier are supported by a strong trussed framework resting on heavy steel axles and broad wheels. The large rear wheels are ratcheted upon the axle, and connected with strong gearing which propels the carrying-belt at right angles to the direction in which the machine is moving.

The wheels and trusses are low and broad, occupying a space 8 feet wide and 14 feet long, exclusive of the side carrier. This enables it to work on hillsides where any wheeled implement can be used; notwithstanding its large size it is so flexible that it may be turned around on a 16-foot embankment. Pilot-wheels and levers enable the operator to raise or lower the plough or carrier at pleasure.

As a motive power, 12 horses—8 driven in front 4 abreast, and 4 in the rear on a push-cart—are usually employed.

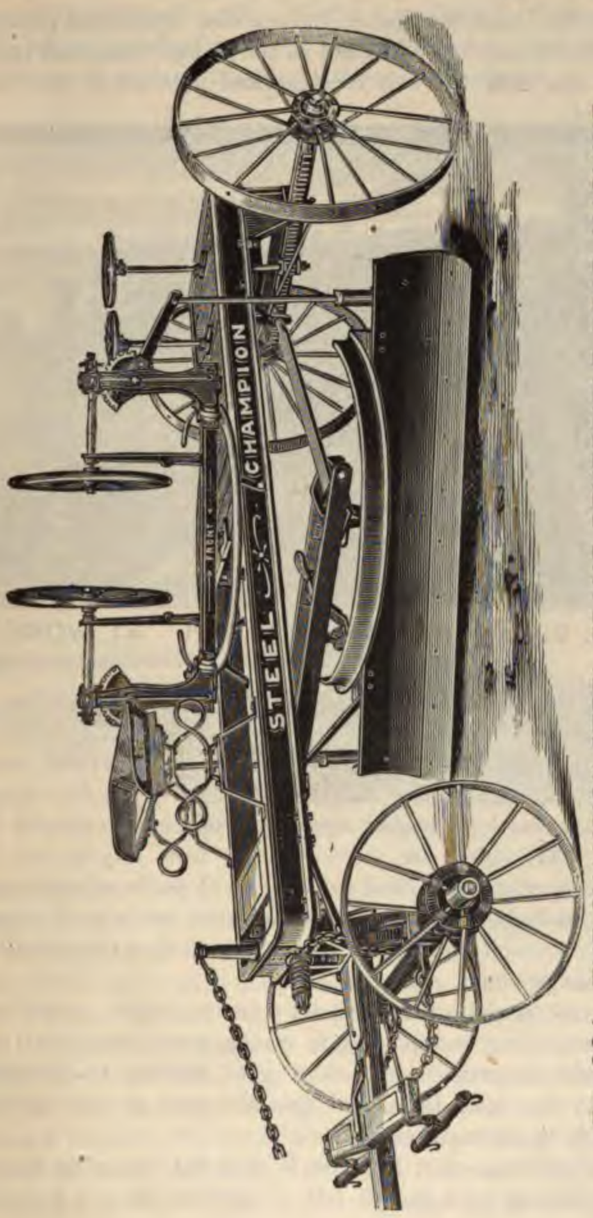


FIG. 204. THE CHAMPION STEEL FRAME REVERSIBLE ROAD MACHINE.

When the teams are started the operator lowers the plough and throws the belting into gear, and as the plough raises and turns the earth to the side the belt receives and delivers it the distance

FIG. 205. "NEW ERA GRADER" AT WORK.

for which the carrier is arranged, forming either excavation or embankment.

When it becomes necessary to deliver the excavated earth beyond the capacity of the machine (22 feet or $7\frac{1}{2}$ feet above the plough) the earth is loaded upon wagons, then conveyed to any distance. Arranging the carrier at 19 feet, wagons are driven under the carrier and loaded with $1\frac{1}{4}$ to $1\frac{1}{2}$ yards of earth in from 20 to 30 seconds. When one wagon turns out with its load, another drives under the carrier, and the machine thus loads 600 to 800 wagons per day.

The makers claim that with six teams and three men it is capable of excavating and placing in embankment from 1000 to 1500 cubic yards of earth in ten hours, or of loading from 600 to 800 wagons in the same time, and that the cost of this handling is from $1\frac{1}{2}$ to $2\frac{1}{2}$ cents per cubic yard.

The *Surface-grader*, Fig. 206, is used for removing earth previously loosened by a plough. It is operated by one horse. The

load may be retained and carried a considerable distance, or it may be spread gradually, as the operator desires. It is also employed to level off and trim the surface after scrapers.

FIG. 206. SURFACE-GRADER.

The blade is of steel, $\frac{1}{4}$ inch thick, 15 inches wide, and 30 inches long. The beam and other parts are of oak and iron. Weight about 60 lbs. Price about $9.

FIG. 207. ROAD-LEVELLER.

The *Road-leveller*, Fig. 207, is used for trimming and smoothing the surface of earth roads. It is largely employed in the spring when the frost leaves the ground.

The blade is of steel, $\frac{1}{4}$ inch thick by 4 inches by 72 inches, and is provided with a seat for the driver. It is operated by a team of horses. Weight about 150 lbs. Price about $12.

1034. Draining-tools.—Fig. 207*a* shows the common form of tools employed for forming and laying tile-drains. They are convenient to use, and expedite the work by avoiding unnecessary excavation.

The tools are used as follows: Nos. 3, 4, and 5 are employed for digging the ditch; Nos. 6 and 7 for cleaning and rounding

the bottom of the ditch for round tile. No. 2 is used for shovelling out loose earth and levelling the bottom of the ditch; No. 1 is used for the same purpose when the ditch is intended for "sole" tile.

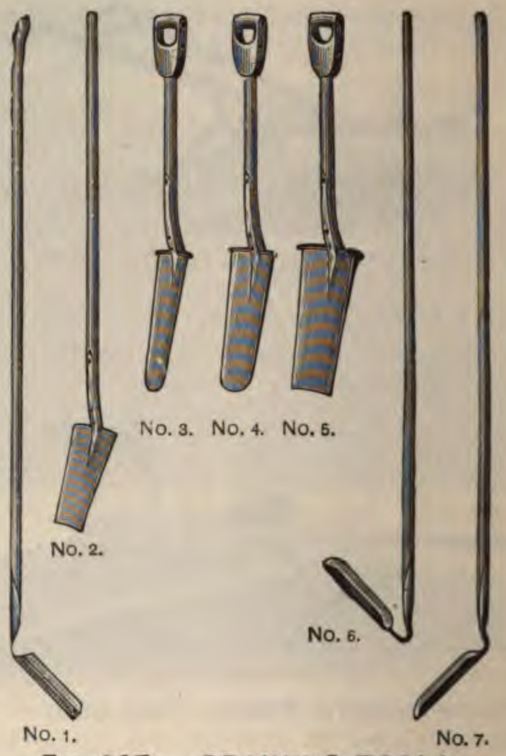


FIG. 207A. DRAINING-TOOLS.

1035. Tools for Rock Excavation.

Hand Drilling.

Drill-steel	per pound	$0.25
Striking-hammers, 3 to 5 pounds	" "	.36
" " 5 pounds and over	" "	.30
Spoons	each	2.00
Wedges	per pound	.12½
Plug and feathers	" "	.30
Crowbars	" "	.10
Stone-sledges	" "	.30
Blacksmith outfit	from $50 upwards.	

Steam Drilling.—A steam-drilling outfit comprises a steam drill; a set of drill-steels; a set of blacksmith's tools for sharpening the drills; a sand-pump; a band for centring piston; extra drill parts; a portable steam boiler; steam hose.

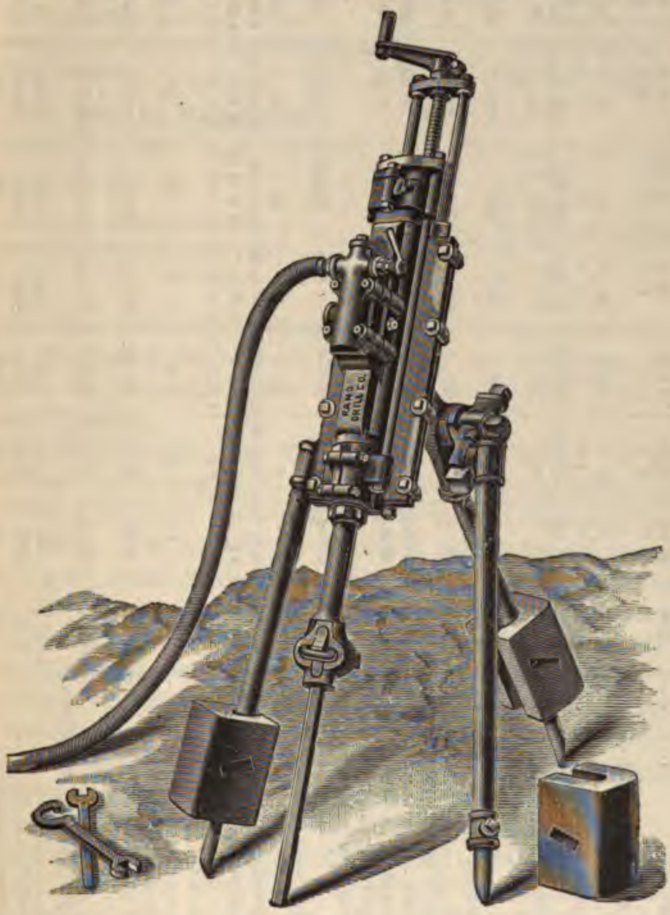


FIG. 208. STEAM DRILL.

Steam drills vary in size, price, etc. as shown in the following table.

Portable boilers range in price from $230 upwards.

DESCRIPTIVE TABLE OF ROCK-DRILLS.

Diameter of cylinder	1¾ in.	2¼ in.	2¾ in.	3 in.	3⅛ in.	3¼ in.	3½ in.	4¼ in.	5 in.
Length of stroke	4 "	5 "	5 "	6 "	6 "	6½ "	6½ "	8 "	3 "
Extreme length of drill from end of crank to end of piston	36 "	42 "	43 "	48 "	48 "	53 "	53 "	60 "	60 "
Diameter of supply-inlet	½ "	¾ "	¾ "	1 "	1 "	1 "	1 "	1 "	1 "
Weight of machine	107 lbs.	175 lbs.	227 lbs.	272 lbs.	273 lbs.	372 lbs.	420 lbs.	620 lbs.	693 lbs.
Weight of tripod, without weights	65 "	155 "	155 "	155 "	198 "	198 "	245 "	260 "	260 "
Shipping weight of drill, tripod, and weights, complete	304 "	645 "	697 "	742 "	786 "	900 "	1019 "	1234 "	1493 "
Approximate strokes per minute, with 60 lbs. pressure at drill	400	360	325	325	325	300	300	250	250
Approximate weight of blow delivered on the rock at each stroke	200 lbs.	350 lbs.	500 lbs.	550 lbs.	625 lbs.	750 lbs.	750 lbs.	1000 lbs.	1500 lbs.
Depth drilled without changing bits	12 in.	20 in.	20 in.	24 in.	24 in.	24 in.	24 in.	30 in.	30 in.
Average work done per 10 hours in granite, down holes, including time lost in setting drill and changing bits	50 feet	50 feet	60 feet	60 feet	70 feet	70 feet	70 feet	70 feet	70 feet
Depth of vertical hole each machine will drill easily ......from 1 to	3 feet	5 "	8 "	12 "	14 "	20 "	20 "	27 "	32 "
Diameter of holes drilled as desired ......from	⅝ to 1¼ in.	1 to 1½ in.	1¼ to 2 in.	1¼ to 2 in.	1¼ to 2½ in.	1½ to 3 in.	1½ to 3 in.	2 to 4 in.	3 to 6 in.
Diameter of drill-steel used	⅝ & ¾ "	1 & ⅞ "	1⅛ & 1 "	1⅛ & 1 "	1¼ & 1⅛ "	1⅜ & 1¼ in.	1⅜ & 1¼ "	1⅝ & 1½ "	1⅝ & 1½ "
Size of shanks	⅝ × 3 "	⅞ × 4½ "	1 × 5 "	1 × 5 "	1⅛ × 5 "	1¼ × 5¾ "	1¼ × 5¾ "	1½ × 6 "	1½ × 6 "
Number of pieces in set of steels to drill holes of depths above stated	3	3	5	6	7	10	10	11	13
Approximate weight of one set steels to drill vertical holes of depths above stated	15 lbs.	29 lbs.	87 lbs.	136 lbs.	224 lbs.	537 lbs.	537 lbs.	1104 lbs.	1521 lbs.
Best size of boiler to give plenty of steam at high pressure	2 to 6 h.p.	8 h. p.	8 h. p.	10 h. p.	10 h. p.	10 to 15 h.p.	10 to 15 h.p.	15 h. p.	15 h. p.
Best size of supply-pipe, carrying steam 100 to 200 feet	¾ to 1 in.	1 in.	1 in.	1 in.	1 in.	1 in.	1 in.	1¼ in.	1¼ in.
Price of drill, unmounted	$145	$225	$250	$275	$300	$325	$325	$375	$425
Price of adjustable tripod, complete	30	50	50	50	50	50	50	55	55
Price of drill and tripod, complete	175	275	300	325	350	375	375	430	480

Steam hose	54 to 97 cents per foot
Drill-steels, per set	$25.00 to $115.00
Blacksmiths' wages for dressing drills	15.00
Forge and hand tools	$50.00 upward
Sand-pumps, each	3.00
Giant blasting-powder, per pound	15 to 60 cents
Leading wires, per foot	1 cent upward
Magneto-electric blasting-apparatus, each	$25.00 to $50.00
Dericks, each	$100.00 upward

1036. Tools for Macadamizing.

Stone-hammers.—The hammers generally used for breaking stone are three, viz.:

Sledges, 5 pounds and over	30 cents per pound
Hand hammers, 3 to 5 pounds	36 " " "
" " 1½ to 2 "	45 " " "

The Ring Gauge, for testing the size of the stone and through which the largest stone should in all positions freely pass, can be made by any blacksmith at a cost of 25 cents. The diameter is usually 2½ inches.

The Straight-edge, Fig. 209, is used for obtaining the proper transverse form of roads. It consists of a horizontal bar having in the centre of its length a plummet for ascertaining when the straight-edge is level. Gauges formed of upright pieces of wood graduated in inches are placed at every four feet; these upright pieces have a slot cut in them so as to allow of their being moved either up or down and adjusted to the desired depths below the horizontal line. These upright pieces are secured to the straight-edge, as shown in the section, by a small bolt passing through the slot in the upright and the straight-edge, the bolt being furnished with a thumbscrew, by tightening which the gauges are fixed in place when adjusted to the required depths.

Lines.—Linen, in rolls 100 feet long; price per dozen rolls, $9.

Reel and Stake.—Price per dozen, $6.00 to $9.50.

Roadbed Roller (Fig. 210).—This is a very efficient form of roller for compacting embankments and the subgrade surface of highways. The roller is 5 feet long with nineteen sections, ten of 35 inches in diameter and nine of 32 inches in diameter, set alternately. The sections act independently on the axle. Weight about 2½ tons. Price $265.

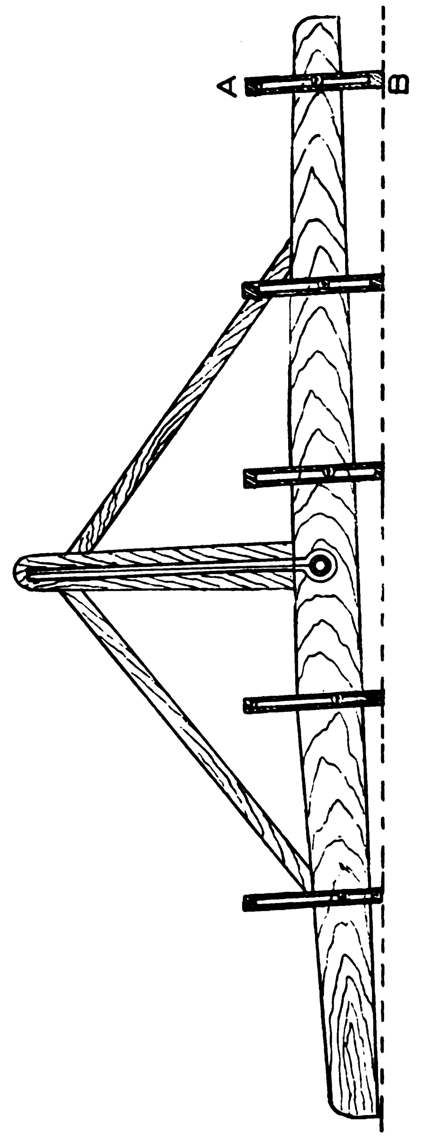
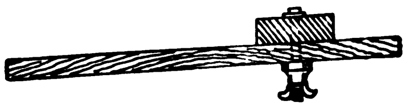


FIG. 209. STRAIGHT-EDGE.



SECTION ON AB.

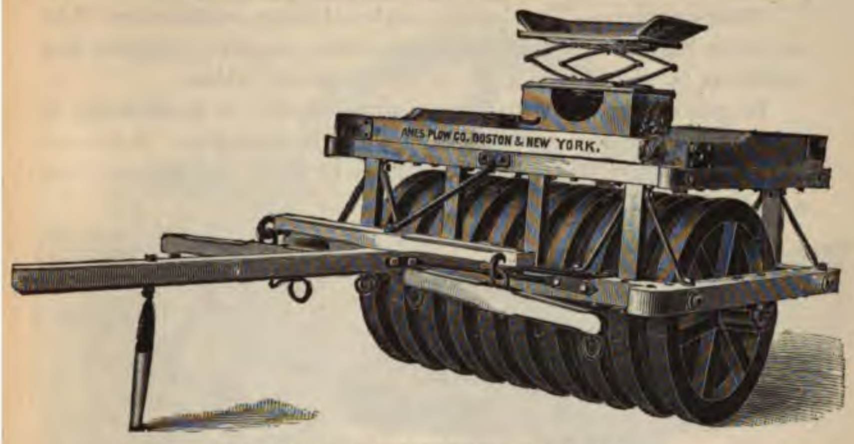


FIG. 210. ROADBED ROLLER.

Sprinkling-carts.—Fig. 211 shows a convenient form of sprinkling-cart either for use on construction or for sprinkling suburban streets and country roads. Capacity about 150 gallons. Price about $100.

FIG. 211. SPRINKLING-CART.

Stone-crushers.—The leading styles of stone crushers are illustrated in Figs. 212 to 215. The dimensions, capacity, weights, and prices (as published) are given in the subjoined tables.

In getting an engine to drive a stone-crusher, it is advisable to obtain one of greater power than is stated in the tables. It is more economical to use 10 H. P. from a 12 or 15 H. P. engine than from a 10 H. P. engine.

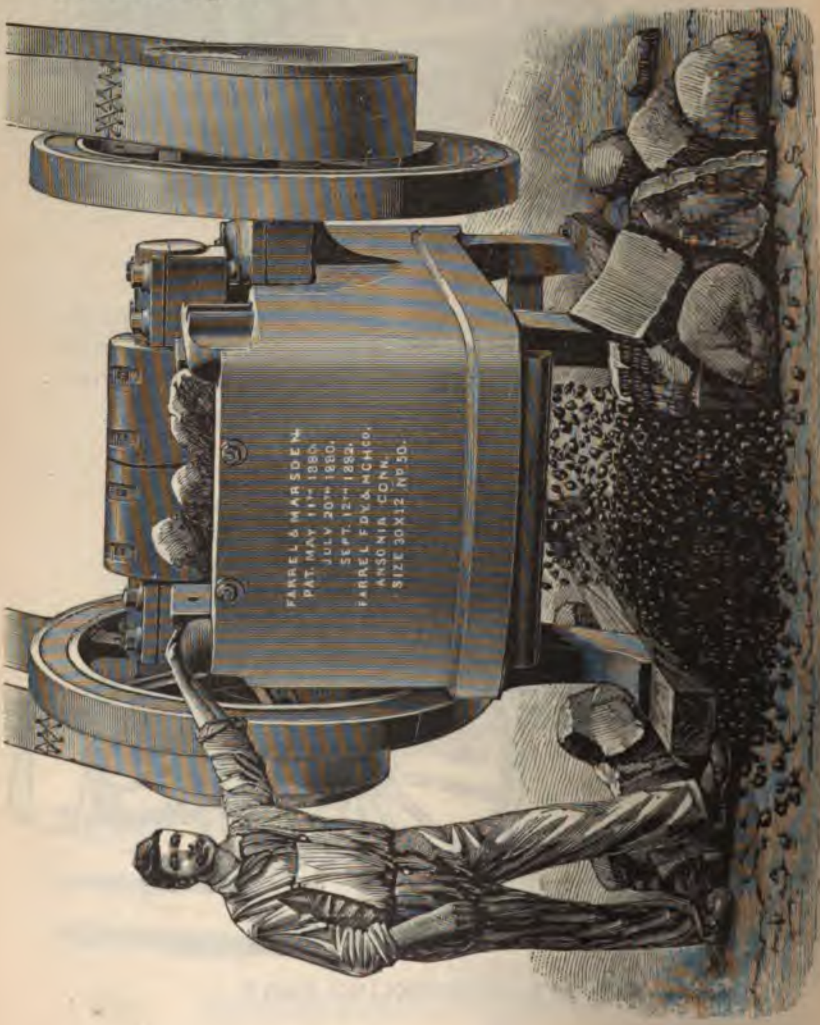


FIG. 212. FARREL MARSDEN CRUSHER.

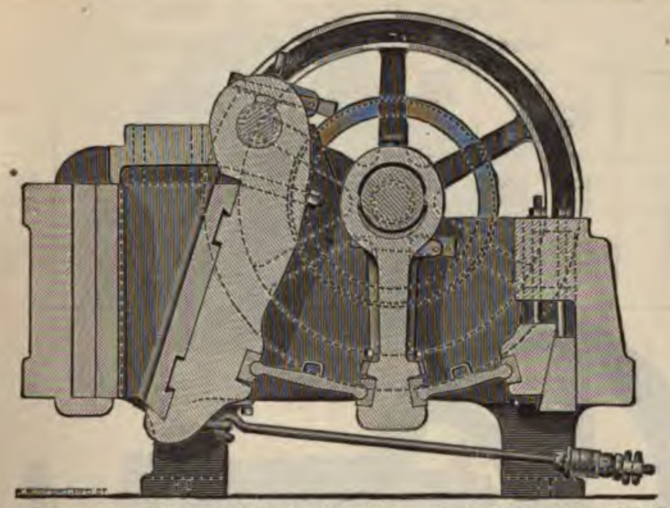


FIG. 212A. SECTIONAL VIEW. FARREL MARSDEN CRUSHER.

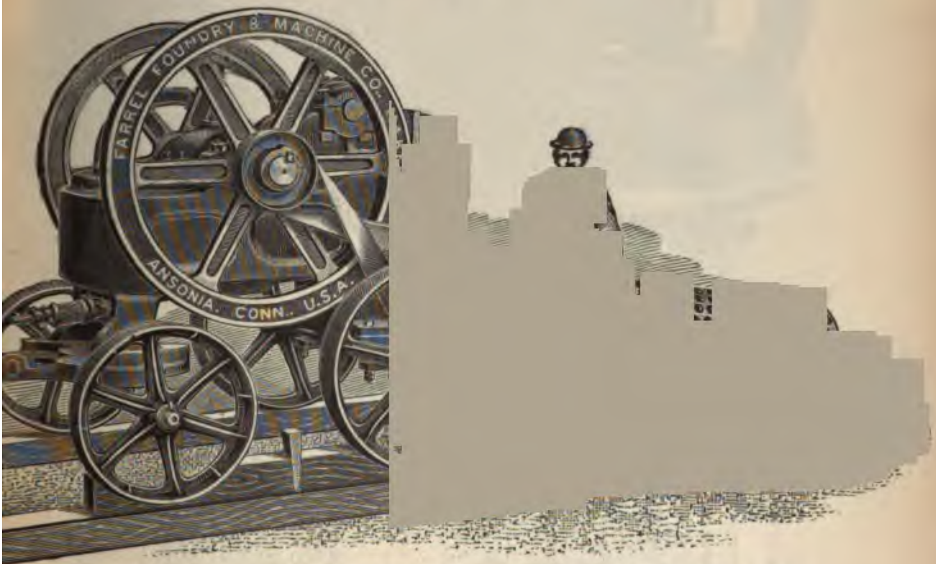


FIG. 212B. FARREL MARSDEN CRUSHER MOUNTED ON WHEELS.

FARREL MARSDEN CRUSHER.

DIMENSIONS, CAPACITY, ETC. (as published).

No.	Receiving Capacity.	Approximate Product of 2″ stone per hour.	Approximate Weight	Horse-power.	Price.
3	10 × 4 in.	3 cubic yards	4,900 lbs.	6	$275.00
4	10 × 7 "	5 " "	7,800 "	12	500.00
5	15 × 9 "	8 " "	14,500 "	15	750.00
6	15 × 10 "	9 " "	15,000 "	15	800.00
8	20 × 10 "	10 " "	17,000 "	20	1050.00

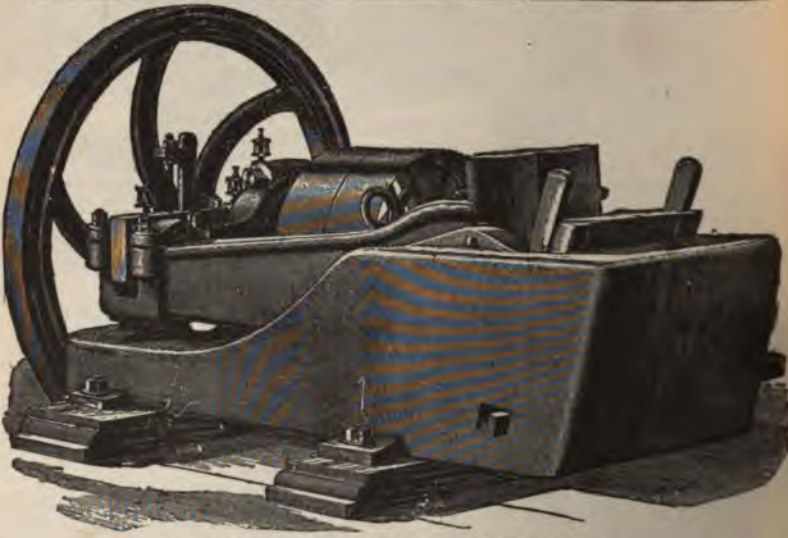


FIG. 213. FORSTER'S CRUSHER.

FORSTER'S CRUSHER.

DIMENSIONS, CAPACITY, ETC. (as published).

No.	Receiving Capacity.	Approximate Product of 2″ stone per hour.	Approximate Weight.	Horse-power.	Price.
1	4 × 9 in.	1 cubic yard	1,800 lbs.	1	$190
2	5 × 15 "	3 " yards	4,500 "	3	390
3	7 × 18 "	5 " "	6,400 "	5	570
4	9 × 28 "	5 " "	8,000 "	6	650
5	12 × 24 "	10 " "	15,000 "	8	1000

FIG. 214. THE BRENNAN CRUSHER.

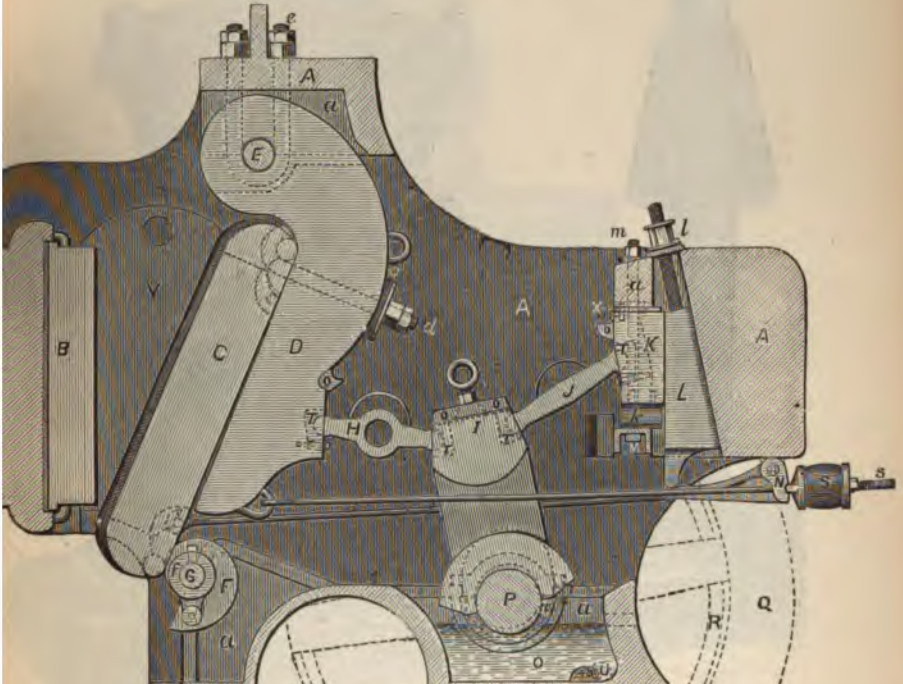


FIG. 214A. THE BRENNAN CRUSHER. SECTIONAL VIEW.

BRENNAN CRUSHER.

DIMENSIONS, CAPACITY, ETC. (as published).

No.	Receiving Capacity.	Approximate Product of 2″ stone per hour.	Approximate Weight.	Horse-power.
1	14 × 48 in.	40 cubic yards	50,000 lbs.	50
2	12 × 37 "	25 " "	32,000 "	40
3	10 × 25 "	15 " "	16,000 "	30
4	8 × 25 "	12 " "	13,000 "	20
5	7 × 20 "	9 " "	10,000 "	15
6	8 × 20 "	4 " "	7,000 "	8

FIG. 215. THE GATES CRUSHER.

GATES CRUSHER.

WEIGHT, CAPACITY, ETC (as published).

Size.	Weight. Pounds.	Capacity. Tons per hour.	Horse-power required.	Price.
0	3,100	2 to 4	4	$400
1	5,500	4 " 8	8	600
2	7,800	6 " 12	12 to 15	800
3	13,500	10 " 20	20 " 30	1200
4	20,000	15 " 30	30 " 40	1900
5	27,000	25 " 40	40 " 50	2500
6	36,000	30 " 60	50 " 60	3500
8	89,000	100 " 150	125 " 150	7000

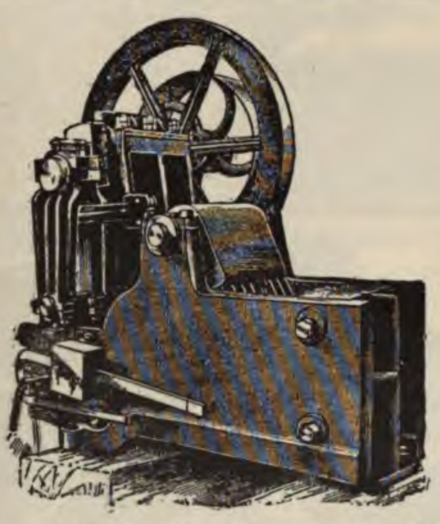


FIG. 215A. SMITH HYDRAULIC SAFETY STONE-CRUSHER.

SMITH'S HYDRAULIC CRUSHER.

WEIGHT, CAPACITY, ETC.

Weight. Pounds.	Capacity. Tons per hour.	Horse-power required.	Price.
5,000	9 to 12	4	$700
7,000	14 " 18	6	850
9,500	20 " 24	8	1100
11,000	25 " 30	12	1500

Revolving Screens vary in diameter from 24 to 48 inches, in length from 5 to 8 feet, in weight from 2000 to 10,500 pounds, in price from $200 to $700.

Wire Screens with wood frames, with meshes ranging from $\frac{1}{4}\times\frac{1}{4}$ to 3×3 inches, cost from $9 to $12.

Stone Forks, used to spread stone instead of a shovel when dirt is present, cost from $10 to $15 per dozen.

Stone Rakes, used for levelling the stones, cost from $14 to $16 per dozen.

Portable Engines, for driving stone-crushers, cost from $850 upwards.

Horse Rollers.—A large variety of horse rollers are on the market, some of which are shown in the following figures.

The Enterprise Roller (Fig. 216).—The standard dimensions of this roller are as follows: Diameter of main roll 50 inches, made in two sections, each 26 inches wide, giving a rolling width of 52 inches; the standard weight is 4 tons, but the ballast-box may be filled with stone and thus loaded to 6 or 8 tons. Price about $100 per ton.

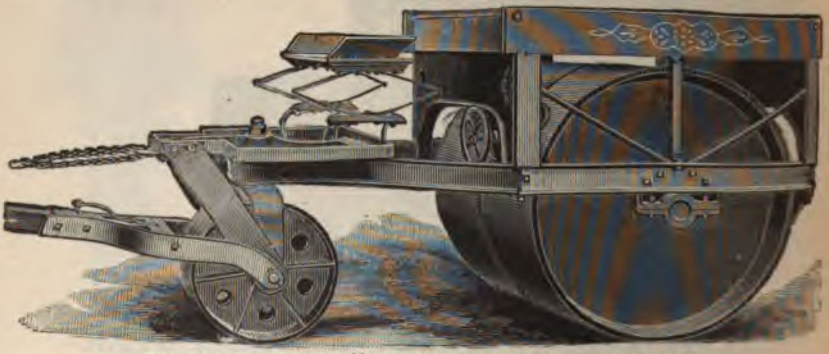


FIG. 216. THE "ENTERPRISE" ROLLER.

Pope's Reversible Road-Roller (Fig. 217).—This roller is made in sizes ranging from 5 to 10 tons. The diameter of the 5-ton roller is 5 feet, and width 5 feet. The diameter of the 10-ton roller is $7\frac{1}{2}$ feet, and width 5 feet. Price $100 per ton.

The Champion Road-Roller (Fig. 218).—This roller is built in three sections, each 14 inches wide, with 1 inch space between the sections, making the track of the roller 44 inches; the diameter of the rolls is 41 inches, and weight 3 tons. Price, 3 tons, $450; 6 tons, $625,

Steam Rollers.—In Fig. 219 is shown the Aveling & Porter Roller. This roller is of English design and manufacture, and may be said to be a pioneer of its type. The first one was con-

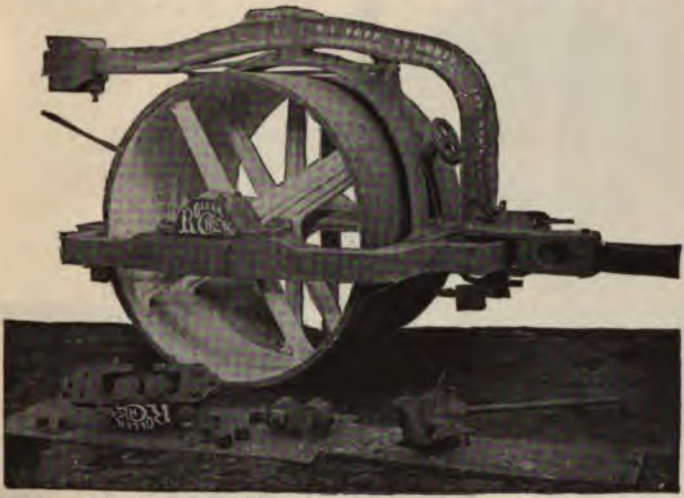


FIG. 217. POPE'S REVERSIBLE ROAD-ROLLER.

structed in 1864; since then, however, many improvements have been made. This firm recently applied the compound engine to road-rollers; this device saves fuel, reduces the noise of the exhaust, and tends to prolong the life of the machine.

This roller is generally used throughout England, as well as in many American and foreign localities.

These machines are made in three sizes, viz., 10, 15, and 20 tons. The principal dimensions are as follows:

AVELING & PORTER ROLLER.

	10-ton.	15-ton.	20-ton.
Diameter of front-roll	45 in.	48 in.	54 in.
" " driving-wheel	66 "	72 "	78 "
Extreme width of machine	78 "	87 "	96 "
Pressure per inch of width	450 lbs., approx.	550 lbs., approx.	650 lbs., approx.
Coal capacity	400 lbs.	450 lbs.	500 lbs.
Water "	150 gal.	200 gal.	250 gal.
Maximum grade ascended with 100 pounds of steam on 6 in. of loose metalling	17%	17%	17%

FIG. 218. THE CHAMPION ROAD-ROLLER.

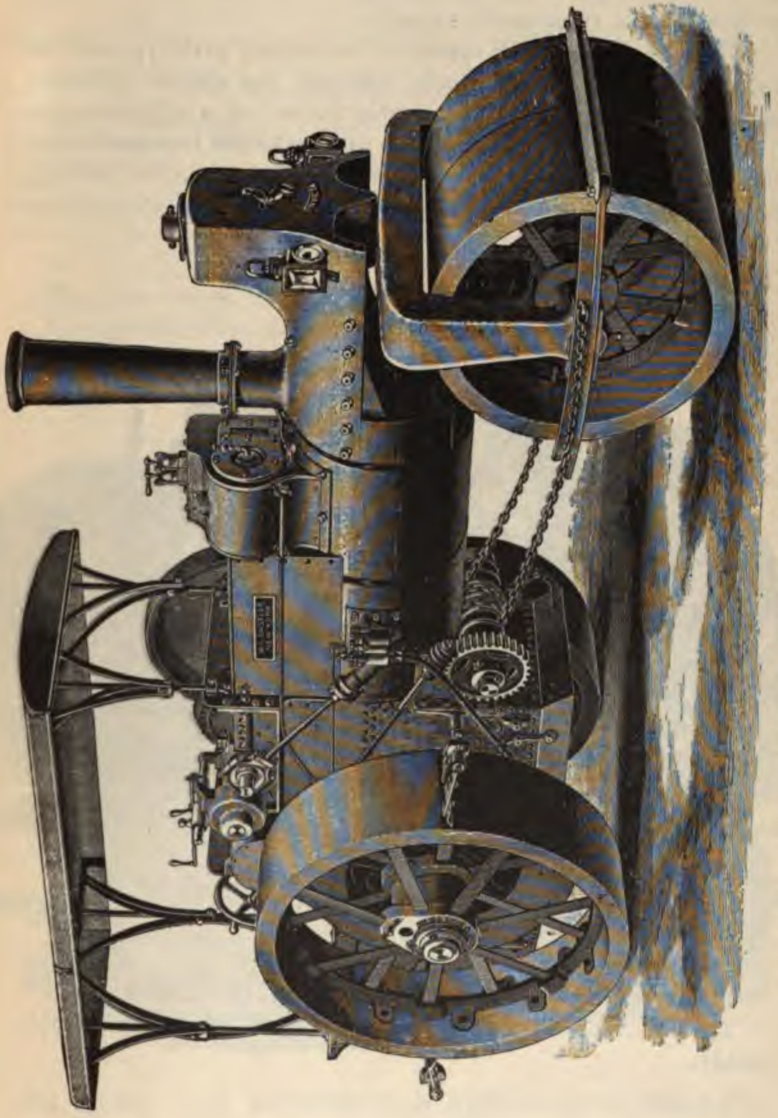


FIG. 219. THE AVELING & PORTER STEAM ROAD-ROLLER.

The Harrisburg Patented Double-engine Roller (Fig. 219*a*).—This roller is of American design and manufacture, and is extensively employed throughout America.

While in appearance it resembles its English prototype, still in many respects it is essentially different, the special difference being in the employment of a double instead of a single engine. It is claimed that the double engine overcomes the principal objection to single engines when applied to rollers, viz., the sticking of the engine on the dead-centres.

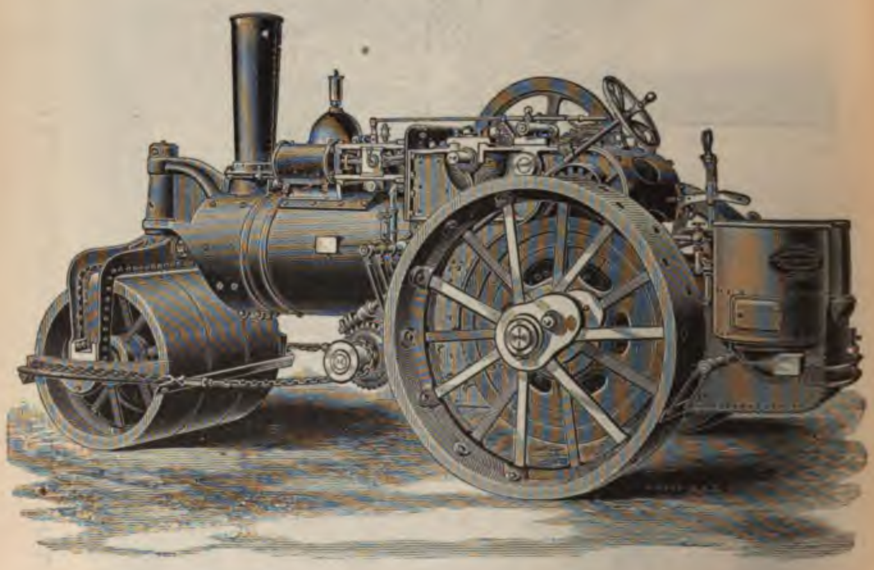


FIG. 219A. THE HARRISBURG DOUBLE-ENGINE STEAM ROAD-ROLLER.

These rollers are made in three sizes, viz., 10, 12, and 15 tons.

The following are some of the principal dimensions (as published):

HARRISBURG ROLLER.

	10-ton.	12-ton.	15-ton.
Width of driving-wheels....................	18 in.	20 in.	22 in.
Pressure per inch of width..................	466 lbs.	500 lbs.	566 lbs.
Coal capacity..........................	400 "	500 "	600 "
Water "	130 gal.	155 gal.	180 gal.
Maximum grade ascended with 120 lbs. of steam	20%	20%	20%

The price ranges from about $4000 for 10-ton rollers upwards.

Springfield Steam Roller (Fig. 219*b*).—These rollers are made in three sizes, viz., 10, 12½, and 15 tons. The principal dimensions are as follows:

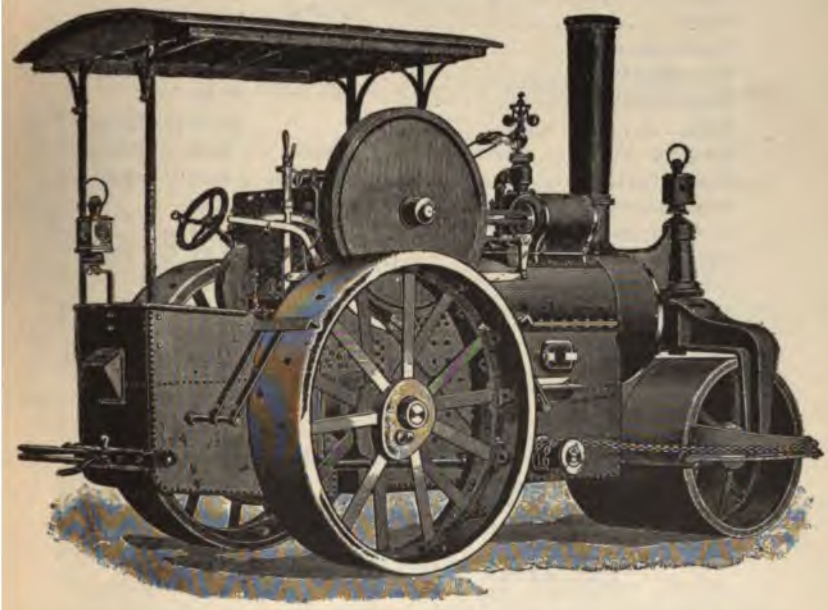


FIG. 219B. THE SPRINGFIELD STEAM ROAD-ROLLER.

SPRINGFIELD ROLLER.

	10-ton.	12½-ton.	15-ton.
Front roll, diameter	4 feet	4 feet	4 feet
Front roll, width	44 inches	48 inches	48 inches
Driving-wheels, diameter	6 feet	6 feet	6 feet
Driving-wheels, width	18 inches	20 inches	22½ inches
Extreme width of machine	75 inches	85 inches	90 inches
Pressure per inch of width	500 pounds	570 pounds	600 pounds
Coal capacity	450 pounds	500 pounds	550 pounds
Water capacity	153 gallons	175 gallons	200 gallons
Maximum grade ascended with 100 pounds stone	16 per ct.	16 per ct.	16 per ct.

1037. Tools employed for the Maintenance of Macadam Roads.

Shovels	per dozen	$7.00 to	$13.50
Picks	" "	10.75 "	22.50
Spades	" "	13.25 "	14.50
Hoes	" "	13.50	
Rakes	" "	14.00 to	16.00
Hand-rammers	each	1.15 "	12.00
Wheelbarrows	per dozen	20.00 "	52.50
Brush-hooks	" "	17.00	
Axes	" "	12.00 to	15.50
Scrapers	each	8.00 "	12.00
Brooms	per dozen	8.50 "	9.00
Stone-sledges	per pound	.30	
Stone-hammers	" "	.45 to	.30
Grass-shears	each	1.63 "	2.63
Turfing axes	"	1.75	
Sod-lifters	"	2.75	
Straight-edges	"	12.00	
Drain-cleaners	per dozen	9.00 to	11.00
Levels	" "	48.00	
Lines	" "	9.00	

1038. Tools employed in the Construction of Block Pavements.

FIG. 219C. PAVER'S HAMMER.

Pavers' hammers (Fig. 219*c*), each $3.
Pavers' crowbars, per pound 12 cents.
Sand-screens, each $4.00 to $4.50.

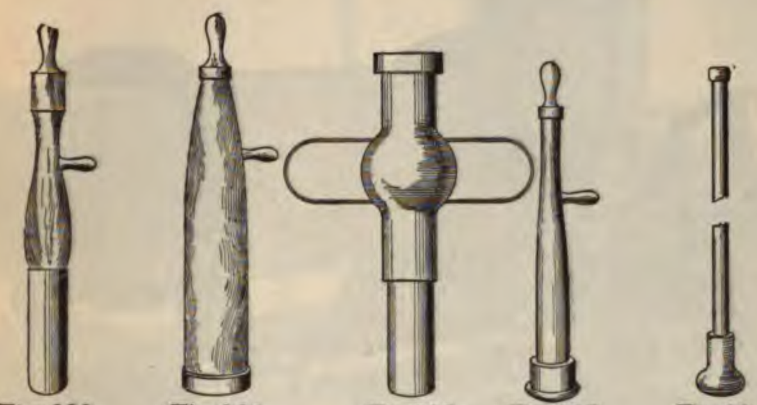


Fig. 220. Fig. 221. Fig. 222. Fig. 223 Fig. 224.

HAND RAMMERS.

Rammers.—The hand rammers are of different forms, as shown in Figs. 220 to 224.

Fig. 220 is made of steel; weighs 45 lbs.; price $9.

Fig. 221 is made of wood, generally locust banded with iron; weighs about 40 lbs.; price $4.00 to $7.50.

Fig. 222 is made of iron, with cast-steel face, locust plug, and hickory handles; weighs from 45 to 55 lbs.; price $9.00 to $12.

Fig. 223 is made of wood, shod with cast-iron or steel; weighs about 27 lbs.; price $3.

Fig. 224 is made of cast-iron, with either wood or iron handle; weighs about 20 lbs.; price $1.15 to $3.00.

Concrete-mixing Machines (Figs. 225 and 225*a*).

Fig. 225.—Price with engine, complete, $950.

Fig. 225*a*.—Price with engine, complete, $1250.

Fig. 225*a*.—Price without engine, $600.

1039. Tools employed for Asphalt Pavements.

The tools employed for compressing the European bituminous pavements are shown in Figs. 227 to 229. The tools are heated and

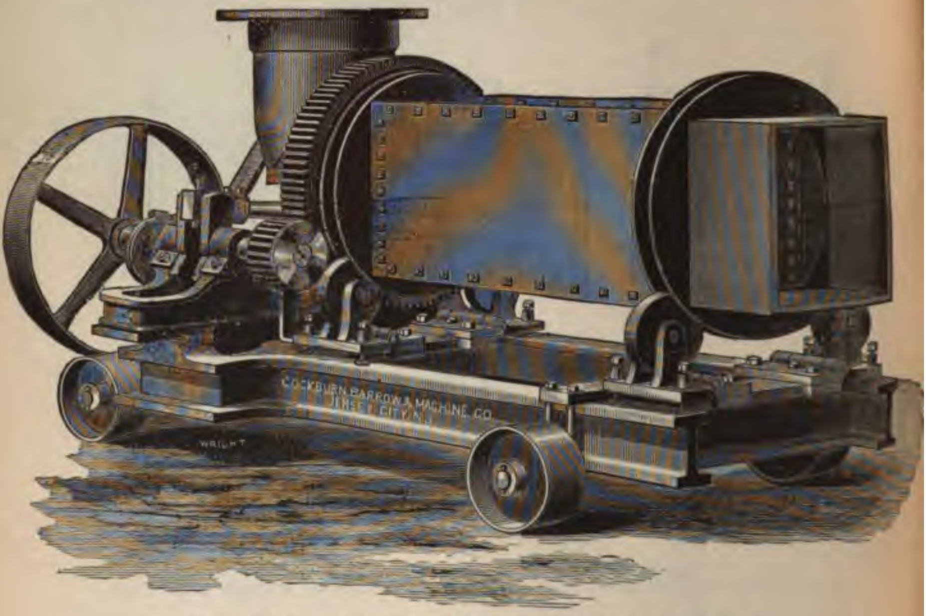


FIG. 225. CONCRETE-MIXING MACHINE.

used as follows. The fouloir (Fig. 229) is used along the junctions of the asphalt with curbs and gutters; the pilon or rammer (Fig. 227) is used for compacting, the operation beginning with light blows and ending with vigorous ones. After the surface is compacted it is rubbed with the lissoir (Fig. 228), after which the surface is dusted with cement and thrown open to traffic.

The roller shown in Fig. 230 is of American design and manufacture, and while principally employed for the compressing of asphalt pavements, it is equally applicable to the consolidation of broken-stone pavements, and the other operations for which steam-rollers are employed. It differs in construction and appearance from the rollers previously described: it has an upright boiler, and two vertical engines that actuate a bevelled gear which works into a gear bolted on the driving-wheel, the tread of which is formed from a 1-inch wrought-iron plate.

These rollers are manufactured in sizes of 5, 7, 10, and 15 tons.

FIG. 285A. CONCRETE-MIXING MACHINE.

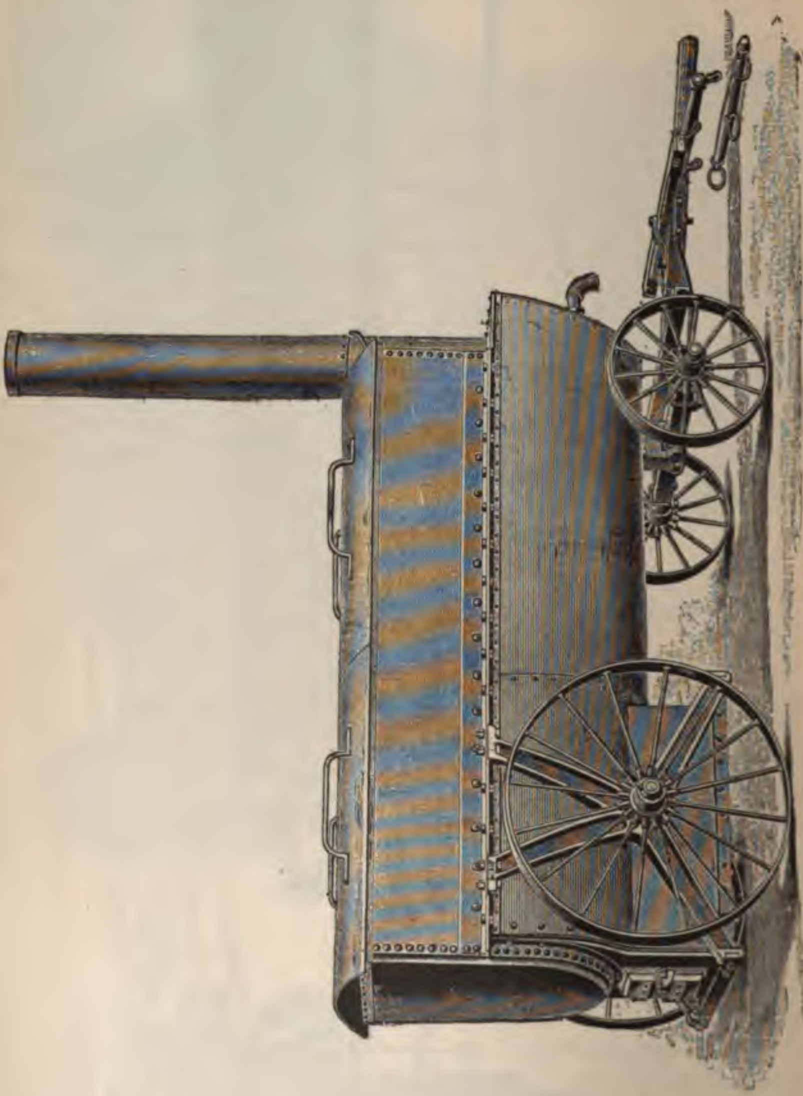


FIG. 226. PORTABLE HEATING-TANK.

Fig.227 PILLON. Fig.228 LISSOIR Fig. 229 FOULOIR.

HAND TOOLS EMPLOYED FOR ASPHALT.

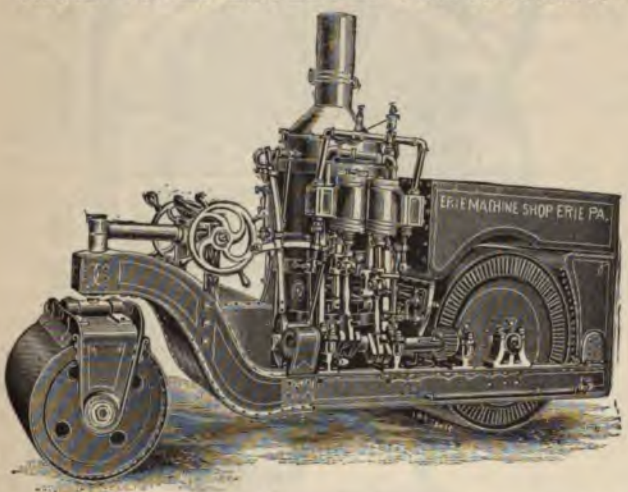


FIG. 230. LINDELOF'S AMERICAN STEAM ROAD-ROLLER.

The principal dimensions of the 5-ton rollers are as follows:

Front roll, diameter	30 inches
Rear roll, "	48 "
Width of roll, front	40 "
" " rear	40 "
Extreme length	14 feet
Boiler tested to	250 lbs.

Water-tank 39 inches wide, $14\frac{1}{2}$ inches on bottom, $18\frac{1}{2}$ inches on top, and 38 inches in height. Price about $1800.

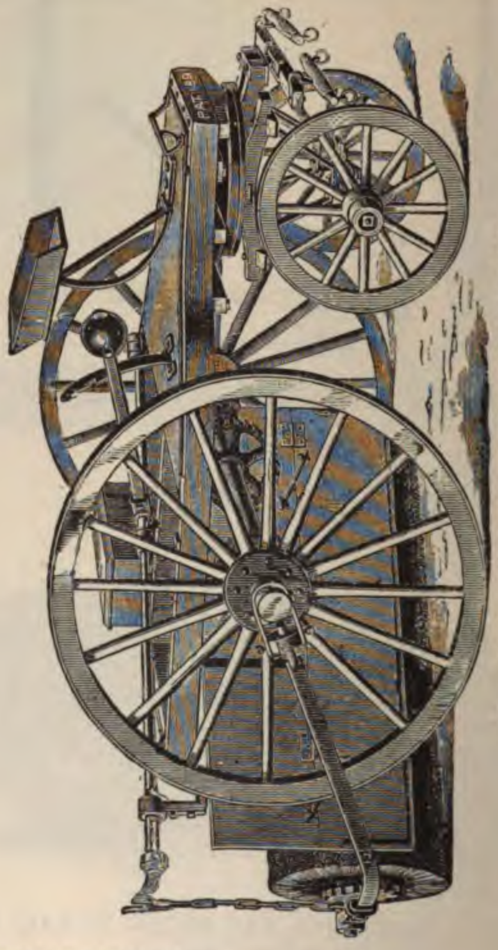


FIG. 231. "PRIDE OF NEW YORK."

1040. Tools for Cleansing.

Hand Tools.—Brooms for street sweeping are made of steel wire or rattan; their size is generally 16 inches long by 4 inches wide; wire lasts longer than rattan, but is only suitable for block pavements.

Price, steel...........................	per dozen	$12.00 to $18.00
" rattan...........................	" "	8.50 " 9.00

Squilgees, or rubber scrapers, are used for cleaning asphalt pavements. Price per dozen, $7.50 to $9.00.

Mechanical Sweepers.—A variety of these machines are in the market, and in various sizes, to be used with one to four horses. Figs. 231 to 234 show a few of the many forms.

The sweeper shown in Fig. 231 is known as the "Pride of New York." The broom is 8 feet 6 inches long, and sweeps a track 7 feet 10 inches wide; it weighs complete 1900 lbs., and is operated by two horses, and costs about $450.00. Smaller machines of the same type are also manufactured, to be operated by one horse; the one-horse machine sweeps a track 5 feet 6 inches wide. Price $300.00.

In Fig. 232 is shown the "Austin" street-sweeper. It is made of steel throughout. The brooms are 9 feet in length, and are covered with an iron and canvas shield to prevent the scattering of the dust. The machine is operated by two horses.

The "Hercules" Combined Sweeper and Sprinkler (Fig. 233) is designed for cleansing either stone, wood, or asphalt pavements. The machine consists of a circular water tank with a revolving brush beneath it. A water pipe or spreader travels in advance of the brush and facilitates its operation.

The sweeper shown in Fig. 234 is known as the "Barnard Castle." It is made in England, and is extensively employed both in that country and in America. It is manufactured in two sizes, viz., to sweep six feet and seven feet six inches, respectively. The smaller machine is made either with shafts for one horse or with a pole for two horses. The larger machine is made only with a pole for two horses.

Scraping-machines—For the removal of stiff mud and snow from pavements scraping-machines are extensively employed. They generally consist of a number of steel or iron teeth three to five inches wide, attached to a frame in such manner that they will rise and pass over any fixed obstacle without suffering injury.

Fig. 235 illustrates the Barnard Castle Street-scraper. It is drawn by either one or two horses, and delivers the mud or snow one side in ridges, similar to the sweeping-machine. The extent of surface scraped per hour by one of these machines is about 8000 square yards.

The scoop used by the street patrol is shown in Fig. 236. The hand cart used by the street patrol in several American cities is shown in Fig. 237.

FIG. 232. THE AUSTIN SWEEPER.

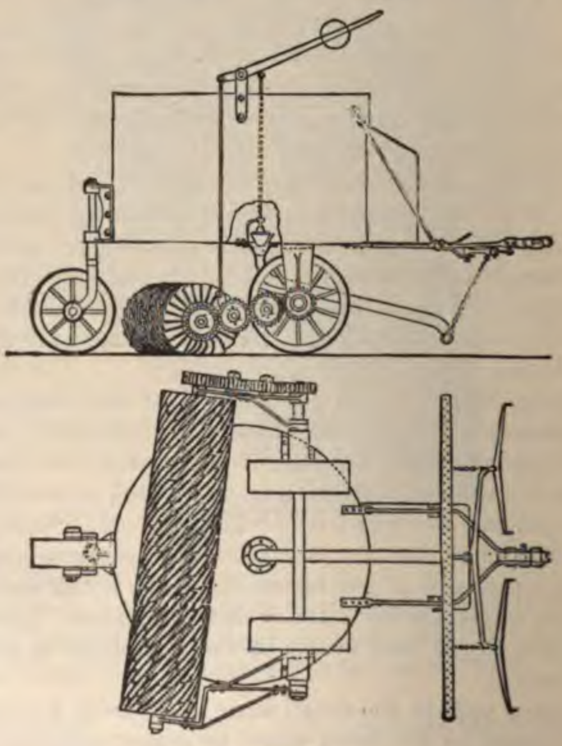


Fig. 233.

THE HERCULES COMBINED SWEEPER AND SPRINKLER.

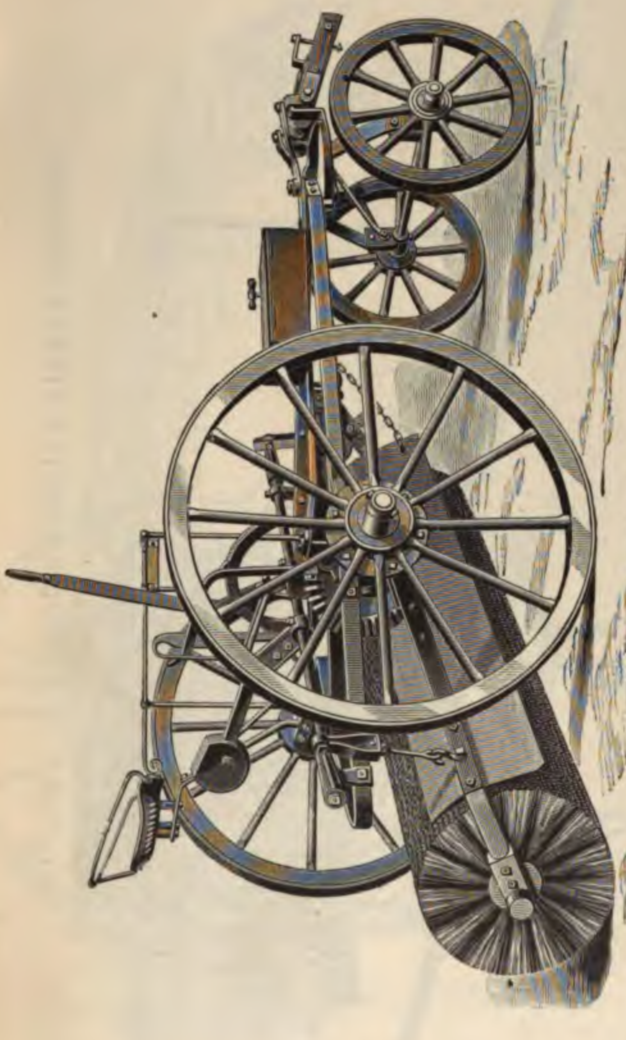


FIG. 234. THE BARNARD CASTLE SWEEPER.

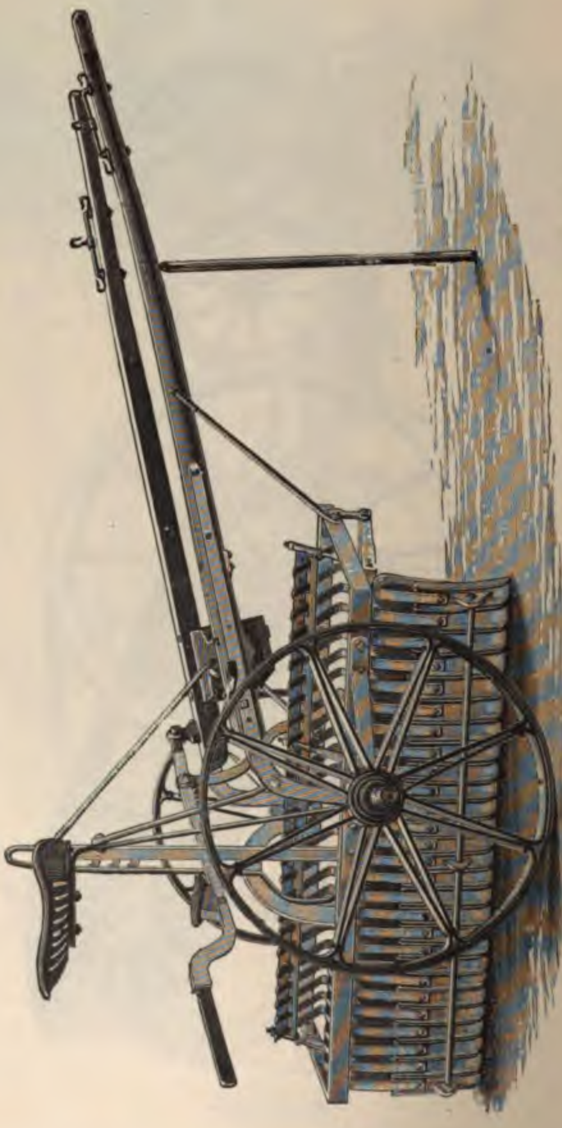


FIG. 235. THE BARNARD CASTLE STREET-SCRAPER.

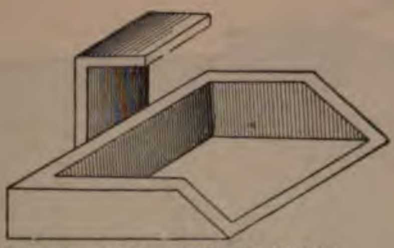


Fig. 236 STREET ORDERLY SCOOP

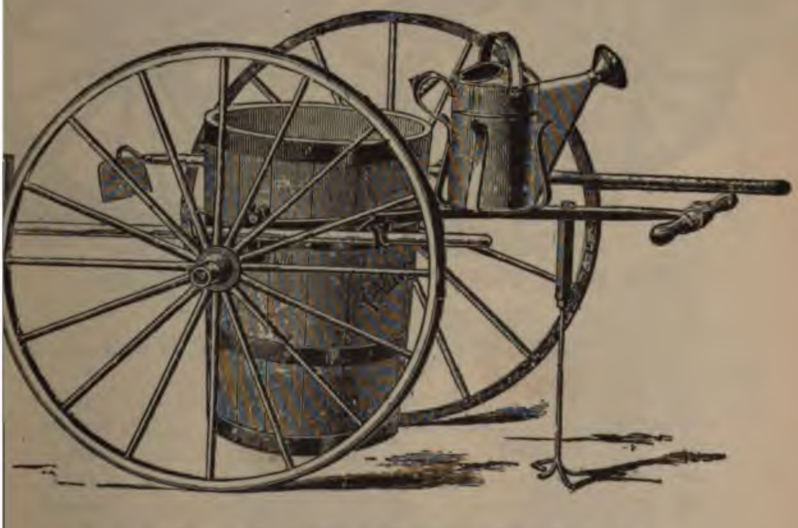


FIG. 237. STREET-PATROL HAND-CART.

Sprinkling-carts. (Figs. 238 to 240.)

FIG. 238. THE STUDEBAKER SPRINKLER.

The Studebaker sprinkler, Figs. 238 and 239, is made in four sizes, viz.:

	Price.
1000 gallons	$550.00
750 "	475.00
550 "	425.00
350 "	400.00

The wagons can be fitted with attachments to spread the water from 16 to 30 feet. These attachments range from $60 to $100.

The rear axle of these sprinklers is longer than the fore axle and can be fitted with wheels having from 3 to 8 inch tires.

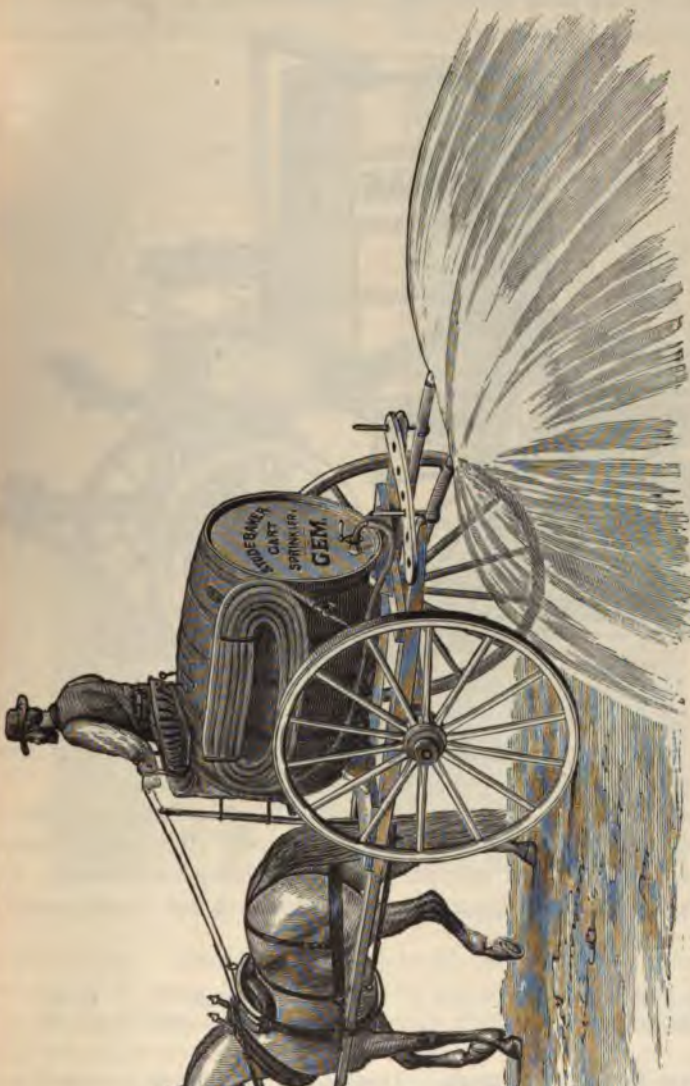


FIG. 239. STUDEBAKER ONE-HORSE SPRINKLER.

A convenient form of sprinkling-cart is shown in Fig. 240. It is made in sizes from 200 to 500 gallons, and will deliver from $\frac{1}{4}$ to $\frac{1}{2}$

FIG. 240.

gallon of water per square yard, the amount delivered being controlled by the driver.

Snow-ploughs.—The ploughs employed for the removal of snow on country highways are usually made of wood. The general form is shown in Figs. 241 and 242. They are loaded with stone. In light falls, say of 6 inches, one horse is sufficient, but in deeper falls two or more are necessary.

Snow-shovels............................	per dozen	\$4.50
Sidewalk-chisels........................	"	\$7.00 to 17.00

1041. Sewer Inlet-traps.—Among the appliances invented for the purpose of closing the street inlets to sewers against the escape of gases, etc., may be mentioned the Hitchcock patent sewer inlet-

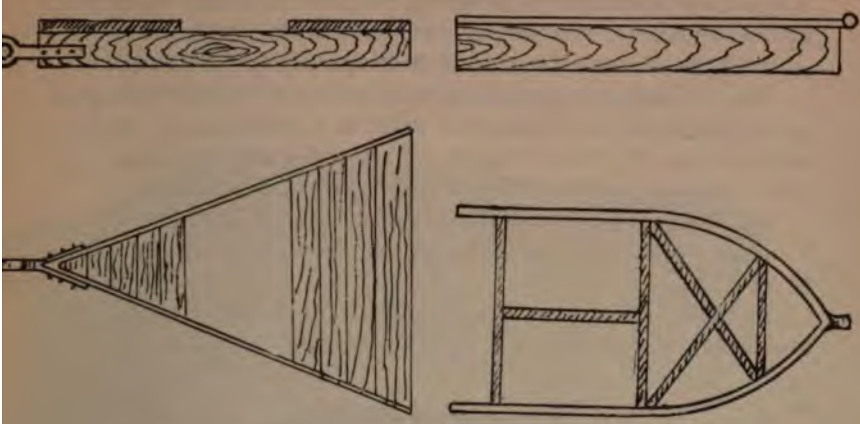


FIG. 241. FIG. 242.

SNOW-PLOUGHS.

FIG. 243. THE HITCHCOCK SEWER INLET-TRAP.

trap, Fig. 243. The device explains itself; the purpose is to prevent the escape of gases from the sewer during the cooler seasons, when the air in the sewer is usually warmer than the air in the streets. The lid *A* opens and permits the discharge of water entering the inlet; but at other times it remains tightly closed by its own weight against the fixed spout *D*. The trap is made of cast-iron, and has been successfully used in Springfield, Mass., for about fifteen years.

The price is about \$4.50; including the grate and rim, which is 18 inches in diameter and weighs about 175 lbs., the price is \$9.

1042. Catch-basin Covers and Gratings. (Figs. 244 to 248.)

Fig. 244 is designed to fit into the hub of a 10-inch drain-pipe, and is suitable for the drainage of walks and private roads. Dimensions on top, 9 inches long, 6 inches wide, and 3 inches deep. Total height $4\frac{1}{2}$ inches. Weight about 20 lbs. Price \$2.50.

Fig. 245 is also adapted for walk-drainage. It is 17 inches long, 9 inches wide, and 8 inches deep. Weight about 57 lbs. Price \$5.50.

Fig. 246 is 28 inches long, $17\frac{1}{2}$ inches wide, and 8 inches deep over flange at bottom. Weight about 214 lbs. Price \$13.

Fig. 244.

Fig. 245.

Fig. 247 is 27 inches long, 14½ inches wide, and 10 inches deep. Weight about 213 lbs. Price $14.

In Fig. 248 are shown other forms of covers and gratings. They are made in sizes from 14 to 36 inches in length.

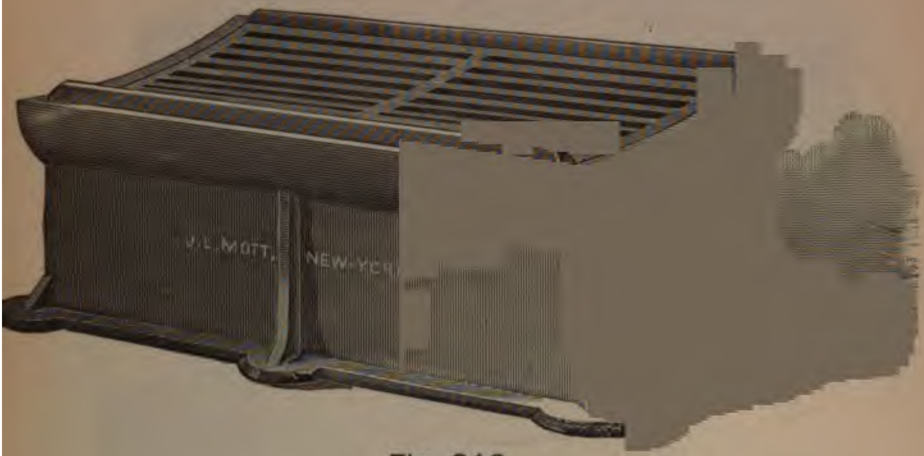


Fig. 246.

(Copyright, 1881, 1883, 1886, 1887, 1889, and 1892, by The J. L. Mott Iron Works.)

Fig. 247.

(Copyright, 1889 and 1892, by The J. L. Mott Iron Works.)

Fig. 249 shows cast-iron gutter-crossings. They are made in sizes ranging from 4×4 inches to 26×9 inches and in lengths to suit the purchaser.

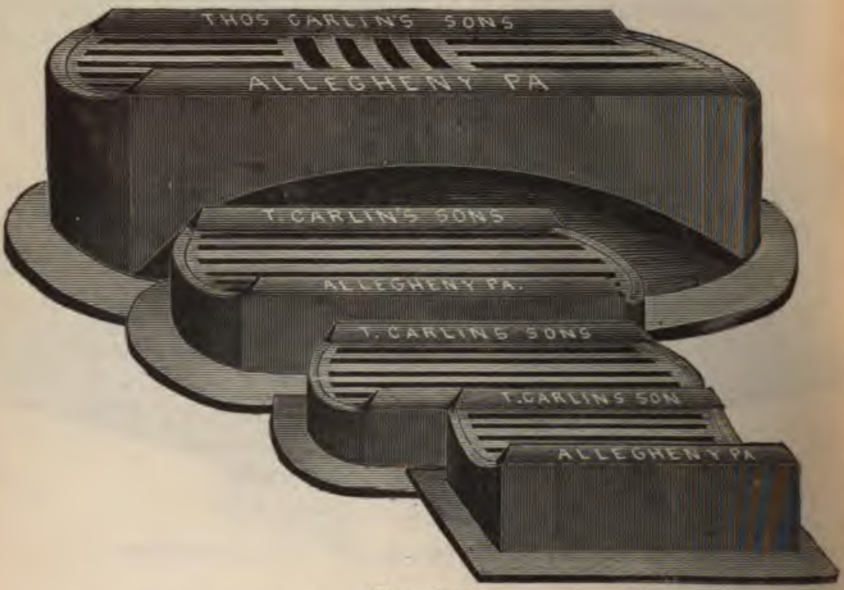


Fig. 248.

1043. Comparison of European and American Prices of Labor.—In comparing the cost of foreign highway construction with American it must be remembered that the cost of labor and materials in European countries is much less than in America.

Table No. LXXXVIII shows the wages paid per day for various kinds of labor in several European localities.

TABLE LXXXVIII.

Kind of Labor.	London.	Berlin.	Paris.	England.‡	Belgium.	France.‡
Unskilled..........	$0.60	$0.48 to $0.70	$0.80	$1.56 to 1.75	$0.06 to $0.07*	$0.58
Foreman..........	$1.00 to $2.00	$0.83	$0.90 to $1.20	$1.00		$20.00†
Paviors..........	$1.75	$1.50	$1.20			
Sweepers..........	$0.80	$0.71	$0.80	$0.80 to 0.90		
Steam-roller drivers.	$1.50		$0.90 to $1.10	$0.80 to 1.44		
Horse and cart.....	$2.00 to $2.50	$1.60 to $1.80		$1.75 to 2.50		$1.55
Masons..........	$1.75	$1.50	$1.60	$1.25		

* Per hour. † Per month. ‡ Average rates outside London and Paris respectively.

In European cities ten hours constitutes a day's labor.

FIG. 249. CAST-IRON GUTTER-CROSSINGS.

1044. Pavements and Horseshoes.—A horse's hoof shod with a heavy iron shoe strikes a blow resembling that struck by a hammer in the hand of man, but with considerably more energy. When the shoes are furnished with sharp toe-pieces and heel-calks, as in the prevailing form, the combined effect of a cutting chisel and hammer is produced. This form of shoe is rendered necessary to obtain foothold on the rough and ill-conditioned pavements generally found in use, but on smooth improved pavements it is not required. Indeed, its use produces exceedingly destructive effects. Broken-stone pavements suffer the most; the surface is excavated and the stones displaced. Block pavements also suffer considerably; the blocks are chipped and rounded until they assume the form of boulders. Wood and asphalt probably suffer the least, unless the blows fall successively in the same place.

The European pavements are not subjected to the destroying effect of this form of shoe. There smooth, flat shoes of light weight are used, and in many localities the form of the shoe is regulated by law.

Flat shoes and wide tires have a large effect in the conservation of pavements, and where improved pavements have been introduced the imposition of a tax would be warranted to hasten their use.

1045. Annual Cost of Structures.—The annual cost of any structure, or the annual payments required to maintain the structure in perpetuity, is composed of three elements:

(1) *Interest on First Cost.*—If the structure is built with borrowed money, interest must be paid as a matter of course and charged against the structure. If it be not borrowed, but furnished by the owner, the case is not essentially different. He takes it from some other investment which would pay interest, and is a loser if the new structure does not make him the same return. Any structure which cannot bear this charge of interest, is a bad investment. But if the structure be neither built nor bought, but inherited by its present owner, its first cost to him is what he could sell it for; if it have no market value, its cost to him is nothing, and he may omit the interest charge entirely.

The general principle is that the cost of any structure is the amount of capital which its owner voluntarily keeps in it, and that on this amount the interest must be charged against the structure.

(2) *Annual Repairs.*—Under this head is included every expense of preserving the property, such as ordinary repairs, watchmen, insurance, etc. If by these means the property is maintained in its original condition, "as good as new," these two elements embrace the whole annual cost. But there are many cases in which this is not true. In spite of the annual repairs, the structure after a time wears out and must be replaced either in whole or in part by a new one. If it be a bridge, it has to be rebuilt; if it be a pavement or a set of rails, they have to be taken up and replaced by new ones. This makes a further payment necessary, viz.:

(3) *Annual Payments to the Renewal Fund.*—By this is meant the proportion of the sum finally needed to renew the structure chargeable to each year. If this fund be raised all at once when it is actually needed, the amount chargeable to each year is the total sum divided by the number of years in the life of the structure. But the amount of each contribution will be made very much smaller if it is actually paid each year and each payment improved at compound interest after the manner of an ordinary sinking fund for the extinction of bonds. This method distributes the burden equally over the whole term and makes it much lighter than is possible in any other way. Taking it for granted that this is the plan adopted, the formula to ascertain the value of these elements will be as follows:

Let $x =$ total annual cost, or the annual payments needed to maintain the structure in perpetuity;

$a =$ first cost:

$b =$ value of old materials when no longer fit for use in the structure, and also the value of so much of the structure as needs no renewal;

$c =$ cost of annual repairs;

$n =$ number of years the structure lasts before renewal;

$r =$ rate of interest on money;

$m =$ amount or final value of an annuity of \$1.00 compounded each year for n years, $= \dfrac{(1+r)^n - 1}{r}$;

The final cost of renewal $= a - b$. If the renewals should exceed first cost, b will equal the excess, and the total cost of renewal will $= a + b$.

To find the annual payment to the renewal fund, call it p.
Then will $1 : m :: p : a - b$.

Whence $p = \frac{a-b}{m} = (a-b) \cdot \frac{r}{(1+r)^n - 1}$.

The annual interest charge will be $= ar$.
The total annual cost of the structure will therefore be

$$x = ar + c + (a-b) \cdot \frac{r}{(1+r)^n - 1}.$$

The factor $(1+r)^n$ is the amount of one dollar at compound interest for n years and is given in Table LXXXIX.

The value of the whole expression $\frac{r}{(1+r)^n - 1}$ is given in Table XC.

As an example of the application of the formula, let the problem be to determine the relative economy of a wooden and an iron bridge for a given place. Let the length of the bridge be 500 feet, or 4 spans of 125 feet each, and let the other data be as follows:

For the wooden bridge
$a =$ first cost $=$ \$25 per foot. $=$ \$12,500;
$b =$ value of iron when the bridge is worn out; $=$ say \$2 per foot. $=$ \$1.000;
$c =$ cost of annual repairs $=$ \$1200;
$n =$ life of the bridge $= 10$ years;
$r = 6$ per cent $= \frac{6}{100}$.
Then will $x =$ \$750 + \$1200 + (\$12,500 × .0759) = \$2822.85.

For the iron bridge
$a =$ first cost $=$ \$50 per foot. $=$ \$25.000.;
$b =$ value of old materials $=$ say \$10 per foot. $=$ \$5000;
$c =$ annual repairs $=$ say \$500;
$n =$ life of bridge $=$ say 60 years;
$r = 6$ per cent $= \frac{6}{100}$.
Then will $x =$ \$1500 + \$500 + (\$20,000 × .0019) = \$2038.

Showing a saving of \$784 per annum by using the iron bridge.

TABLE LXXXIX.

VALUE OF $(1 + r)^n$, OR THE AMOUNT OF $1 AT COMPOUND INTEREST FOR A TERM OF YEARS.

Interest 2 per cent.

Years.	Value.	Years.	Value.	Years.	Value.
1	$1.020	21	$1.516	41	$2.252
2	1.040	22	1.546	42	2.297
3	1.061	23	1.577	43	2.343
4	1.082	24	1.608	44	2.390
5	1.104	25	1.641	45	2.438
6	1.126	26	1.673	46	2.487
7	1.149	27	1.707	47	2.536
8	1.172	28	1.741	48	2.587
9	1.195	29	1.776	49	2.639
10	1.219	30	1.811	50	2 692
11	1.243	31	1.848	55	2.972
12	1.268	32	1.885	60	3.281
13	1.294	33	1.922	65	3.623
14	1.319	34	1.961	70	4.000
15	1.346	35	2.000	75	4.416
16	1.373	36	2.040	80	4.875
17	1.400	37	2.081	85	5.383
18	1.428	38	2.122	90	5.943
19	1.457	39	2.165	95	6.562
20	1.486	40	2.208	100	7.245

Interest 3 per cent.

Years.	Value.	Years.	Value.	Years.	Value.
1	$1.030	21	$1.860	41	$3.360
2	1.061	22	1.916	42	3.461
3	1.093	23	1.974	43	3.565
4	1.126	24	2.033	44	3.671
5	1.159	25	2.094	45	3.782
6	1.194	26	2.157	46	3.895
7	1.230	27	2.221	47	4.012
8	1.267	28	2.288	48	4.132
9	1.305	29	2.357	49	4.256
10	1.344	30	2.427	50	4 384
11	1.384	31	2.500	55	5.082
12	1.426	32	2.575	60	5.892
13	1.469	33	2.652	65	6.830
14	1.513	34	2.732	70	7.918
15	1.558	35	2.814	75	9.179
16	1.605	36	2.898	80	10.641
17	1.653	37	2.985	85	12.336
18	1.702	38	3.075	90	14.300
19	1.754	39	3.167	95	16.578
20	1.806	40	3.262	100	19.219

VALUE OF $(1+r)^n$. (*Continued.*)

Interest 3½ *per cent.*

Years.	Value.	Years.	Value.	Years.	Value.
1	$1.035	21	$2.059	41	$4.098
2	1.071	22	2.132	42	4.241
3	1.109	23	2.206	43	4.390
4	1.148	24	2.283	44	4.543
5	1.188	25	2.363	45	4.702
6	1.229	26	2.446	46	4.867
7	1.272	27	2.532	47	5.037
8	1.317	28	2.620	48	5.214
9	1.363	29	2.712	49	5.396
10	1.411	30	2.807	50	5.585
11	1.460	31	2.905	55	6.633
12	1.511	32	3.007	60	7.878
13	1.564	33	3.112	65	9.357
14	1.619	34	3.221	70	11.113
15	1.675	35	3.334	75	13.199
16	1.734	36	3.450	80	15.676
17	1.795	37	3.571	85	18.618
18	1.857	38	3.696	90	22.112
19	1.923	39	3.825	95	26.262
20	1.990	40	3.959	100	31.191

Interest 4 *per cent.*

1	$1.040	21	$2.279	41	$4.993
2	1.082	22	2.370	42	5.193
3	1.125	23	2.465	43	5.400
4	1.170	24	2.563	44	5.617
5	1.217	25	2.666	45	5.841
6	1.265	26	2.772	46	6.075
7	1.316	27	2.883	47	6.318
8	1.369	28	2.999	48	6.571
9	1.423	29	3.119	49	6.833
10	1.480	30	3.243	50	7.107
11	1.539	31	3.373	55	8.646
12	1.601	32	3.508	60	10.520
13	1.665	33	3.648	65	12.799
14	1.732	34	3.794	70	15.572
15	1.801	35	3.946	75	18.945
16	1.873	36	4.104	80	23.050
17	1.948	37	4.268	85	28.044
18	2.026	38	4.439	90	34.119
19	2.107	39	4.616	95	41.511
20	2.191	40	4.801	100	50.505

VALUE OF $(1+r)^n$. (*Continued.*)

Interest 4½ *per cent.*

Years.	Value.	Years.	Value.	Years.	Value.
1	$1.045	21	$2.520	41	$6.078
2	1.092	22	2.634	42	6.352
3	1.141	23	2.752	43	6.637
4	1.193	24	2.876	44	6.936
5	1.246	25	3.005	45	7.248
6	1.302	26	3.141	46	7.574
7	1.361	27	3.282	47	7.915
8	1.422	28	3.430	48	8.271
9	1.486	29	3.584	49	8.644
10	1.553	30	3.745	50	9.033
11	1.623	31	3.914	55	11.256
12	1.696	32	4.090	60	14.027
13	1.772	33	4.274	65	17.481
14	1.852	34	4.466	70	21.784
15	1.935	35	4.667	75	27.147
16	2.022	36	4.877	80	33.830
17	2.113	37	5.097	85	42.158
18	2.208	38	5.326	90	52.537
19	2.308	39	5.566	95	65.471
20	2.412	40	5.816	100	81.589

Interest 5 *per cent.*

1	$1.050	21	$2.786	41	$7.392
2	1.103	22	2.925	42	7.762
3	1.158	23	3.072	43	8.150
4	1.216	24	3.225	44	8.557
5	1.276	25	3.386	45	8.985
6	1.340	26	3.556	46	9.434
7	1.407	27	3.733	47	9.906
8	1.477	28	3.920	48	10.401
9	1.551	29	4.116	49	10.921
10	1.629	30	4.322	50	11.467
11	1.710	31	4.538	55	14.636
12	1.796	32	4.765	60	18.679
13	1.886	33	5.003	65	23.840
14	1.980	34	5.253	70	30.426
15	2.079	35	5.516	75	38.833
16	2.183	36	5.792	80	49.561
17	2.292	37	6.081	85	63.254
18	2.407	38	6.385	90	80.730
19	2 527	39	6.705	95	103.035
20	2.653	40	7.040	100	131.501

VALUE OF $(1 + r)^n$. (*Continued.*)

Interest 6 per cent.

Years.	Value.	Years.	Value.	Years.	Value.
1	$1.060	21	$3.400	41	$10.903
2	1.124	22	3.604	42	11.557
3	1.191	23	3.820	43	12.250
4	1.262	24	4.049	44	12.985
5	1.338	25	4.292	45	13.765
6	1.419	26	4.549	46	14.590
7	1.504	27	4.822	47	15.466
8	1.594	28	5.112	48	16.394
9	1.689	29	5.418	49	17.378
10	1.791	30	5.743	50	18.420
11	1.898	31	6.088	55	24.650
12	2.012	32	6.453	60	32.988
13	2.133	33	6.841	65	44.145
14	2.261	34	7.251	70	59.076
15	2.397	35	7.686	75	79.057
16	2.540	36	8.147	80	105.796
17	2.693	37	8.636	85	141.579
18	2.854	38	9.154	90	189.465
19	3.026	39	9.704	95	253.546
20	3.207	40	10.286	100	339.302

TABLE XC.

VALUE OF $\frac{r}{(1 + r)^n - 1}$, OR THE SINKING FUND THAT WITH COMPOUND INTEREST WILL AMOUNT TO ONE DOLLAR AT THE END OF A TERM OF YEARS.

Interest 3 per cent.

Years.	Value.	Years.	Value.	Years.	Value.
1	$1.0000	21	$0.0349	41	$0.0127
2	.4926	22	.0327	42	.0122
3	.3235	23	.0308	43	.0117
4	.2390	24	.0290	44	.0112
5	.1884	25	.0274	45	.0108
6	.1546	26	.0259	46	.0104
7	.1305	27	.0246	47	.0100
8	.1125	28	.0233	48	.0096
9	.0984	29	.0221	49	.0092
10	.0872	30	.0210	50	.0089
11	.0781	31	.0200	55	.0073
12	.0705	32	.0190	60	.0061
13	.0640	33	.0182	65	.0051
14	.0585	34	.0173	70	.0043
15	.0538	35	.0165	75	.0037
16	.0496	36	.0158	80	.0031
17	.0460	37	.0151	85	.0026
18	.0427	38	.0145	90	.0023
19	.0398	39	.0138	95	.0019
20	.0372	40	.0133	100	.0016

VALUE OF $\frac{r}{(1+r)^n - 1}$. (*Continued.*)

Interest 3½ *per cent.*

Years.	Value.	Years.	Value.	Years.	Value.
1	$1.0000	21	$0.0330	41	$0.0113
2	.4914	22	.0309	42	.0108
3	.3219	23	.0290	43	.0103
4	.2373	24	.0273	44	.0099
5	.1865	25	.0257	45	.0095
6	.1527	26	.0242	46	.0091
7	.1285	27	.0229	47	.0087
8	.1105	28	.0216	48	.0083
9	.0964	29	.0204	49	.0080
10	.0852	30	.0194	50	.0076
11	.0761	31	.0184	55	.0062
12	.0685	32	.0174	60	.0051
13	.0621	33	.0166	65	.0042
14	.0566	34	.0158	70	.0035
15	.0518	35	.0150	75	.0029
16	.0477	36	.0143	80	.0024
17	.0440	37	.0136	85	.0020
18	.0408	38	.0130	90	.0017
19	.0379	39	.0124	95	.0014
20	.0354	40	.0118	100	.0012

Interest 4 *per cent.*

1	$1.0000	21	$0.0313	41	$0.0100
2	.4902	22	.0292	42	.0095
3	.3204	23	.0273	43	.0091
4	.2255	24	.0256	44	.0087
5	.1846	25	.0240	45	.0083
6	.1508	26	.0226	46	.0079
7	.1266	27	.0212	47	.0075
8	.1085	28	.0200	48	.0072
9	.0945	29	.0189	49	.0069
10	.0833	30	.0178	50	.0066
11	.0742	31	.0169	55	.0052
12	.0666	32	.0160	60	.0042
13	.0604	33	.0151	65	.0034
14	.0547	34	.0143	70	.0027
15	.0499	35	.0136	75	.0022
16	.0458	36	.0129	80	.0018
17	.0422	37	.0122	85	.0015
18	.0390	38	.0116	90	.0012
19	.0361	39	.0111	95	.0010
20	.0336	40	.0105	100	.0008

VALUE OF $\frac{r}{(1+r)^n - 1}$. (*Continued.*)

Interest 5 *per cent.*

Years.	Value.	Years.	Value.	Years.	Value.
1	$1.0000	21	$0 0280	41	$0.0078
2	.4878	22	.0260	42	.0074
3	.3172	23	.0241	43	.0070
4	.2320	24	.0225	44	.0066
5	.1810	25	.0210	45	.0063
6	.1470	26	.0196	46	.0059
7	.1228	27	.0183	47	.0056
8	.1047	28	.0171	48	.0053
9	.0907	29	.0160	49	.0050
10	.0795	30	.0151	50	.0048
11	.0704	31	.0141	55	.0037
12	.0628	32	.0133	60	.0028
13	.0565	33	.0125	65	.0022
14	.0510	34	.0118	70	.0017
15	.0463	35	.0111	75	.0013
16	.0423	36	.0104	80	.0010
17	.0387	37	.0098	85	.0008
18	.0355	38	.0093	90	.0006
19	.0327	39	.0088	95	.0005
20	.0302	40	.0083	100	.0004

Interest 6 *per cent.*

1	$1.0000	21	$0.0250	41	$0.0061
2	.4854	22	.0230	42	.0057
3	.3141	23	.0213	43	.0053
4	.2286	24	.0197	44	.0050
5	.1774	25	.0182	45	.0047
6	.1434	26	.0169	46	.0044
7	.1191	27	.0157	47	.0041
8	.1010	28	.0146	48	.0039
9	.0870	29	.0136	49	.0037
10	.0759	30	.0126	50	.0034
11	.0668	31	.0118	55	.0025
12	.0593	32	.0110	60	.0019
13	.0530	33	.0103	65	.0014
14	.0476	34	.0096	70	.0010
15	.0430	35	.0090	75	.0008
16	.0390	36	.0084	80	.0006
17	.0354	37	.0079	85	.0004
18	.0324	38	.0074	90	.0003
19	.0296	39	.0069	95	.0002
20	.0272	40	.0065	100	.0002

APPENDIX.

I.

NAMING AND NUMBERING COUNTRY ROADS AND HOUSES.

1. THE naming of country roads and the numbering of country houses has not generally received that recognition which its importance demands ; consequently commercial and social intercourse in rural sections is rendered extremely inconvenient. The indifference of rural communities on this subject has been due to several causes, but mainly to the want of a system which was applicable to all localities, and which should, without serious complication, be sufficiently elastic to cover the changes wrought by improvement. Such a system is now available. It is known as the "*Ten-block Method*," devised by Mr. A. L. Bancroft, and now in successful use in Contra Costa County, Cal.

2. *The Ten-block System.*—In this system the roads are first named in as long lengths as possible (names of towns or living residents are not used,—some landscape feature or historical association suggesting the name) and then carefully measured. The point from which the measurements of all roads within the county are commenced is the centre of the roadway directly in front of the main entrance to the county court-house; each mile is divided into 10 blocks of 528 feet, and each block is numbered, the even numbers being placed on the right-hand side and the odd ones on the left-hand side going from the court-house; the block numbers are conspicuously marked on the fences or on posts specially placed for the purpose; a line indicating the division of the block is placed between the numbers thus, 52 | 50; the end of each mile is indicated by an X painted inside a circle, the half-mile is marked by a V in a semicircle; the houses in each block have the same numbers as the block on which they stand, but are distinguished by a letter of the alphabet affixed thereto, as 3A, 3B, to 3Z ; thus when new

houses are built in the block they can have numbers assigned to them without interfering with those already numbered; the number of roads entering or intersecting a given road makes no difference with the length or number of the block; in passing through villages or towns the names and numbers already in use are left unchanged, but outside the town limits the ten-block system is resumed, the first house having a number depending upon its distance from the court-house. In this way, although a road passes through a dozen towns, the numbers on each side of the town indicate the true position of the house and its distance from the commencement of the road. The distance from the court-house or between any two given houses is quickly ascertained by dividing half the even numbers by 10; for instances, if a house is numbered 506, its distance from the county court-house is $\frac{506}{2} = \frac{253}{10} = 25\frac{3}{10}$ miles, or the distance of the same house beyond another house numbered 315 is equal to $\frac{506}{2} - \frac{315}{2} = \frac{253 - 157}{10} = 9\frac{6}{10}$ miles, and on the opposite side of the road.

3. The data necessary to put this system in operation are contained in the following ordinance of the Board of Supervisors of the county of Contra Costa, Cal.:

An ordinance of the Board of Supervisors of the county of Contra Costa, State of California, naming the several public highways of the county and authorizing the use of certain other names and designations for private or local roads in use in said county; also providing for the erection and due preservation of suitable guide-boards at all road crossings and intersections, and at other necessary or suitable points upon such roads as have been properly measured or divided into blocks, according to the "Ten-block System," also providing for the affixing and maintaining by residents of house or farm-entrance numbers, based thereon, for all country residences upon such measured roads; also providing for an official road map of the county, and other records.

The Board of Supervisors of the County of Contra Costa do ordain as follows:

SECTION 1. All public highways which have been duly accepted

by the county shall hereafter be known and designated by the names prescribed in this ordinance, according to the designation and descriptions laid down in Section 29.

SEC. 2. All private or local roads designated in Sec. 29 of this ordinance shall in all official reference thereto be hereafter known by the names herein prescribed, and the public use and recognition of such designation is hereby recommended.

SEC. 3. Whenever the owner or owners of any strip or strips of land within the county shall represent to the Board of Supervisors their purpose and wish to devote the same to use as a public or private road, or as a right of way for access to any dwelling, and shall offer or accept a name for the same, approved by the road committee, to be appointed or confirmed by the Board of Supervisors, and shall comply with the provisions of the law respecting roads, such road name shall, when approved by the Board of Supervisors, be thereafter used in all official reference to the same, and its public use shall be recommended. Such road shall then be listed in the road list and given a designating number and letter immediately following the number of the road to which it is adjacent or tributary, until such time as the Board of Supervisors shall revise the list and renumber the roads. And such road shall thereafter come under the provisions of this ordinance the same as the roads enumerated.

SEC. 4. The streets of all unincorporated towns or villages in the county may come within the provisions of this ordinance and be named. When numbered, the numbers to be according to the town method of 100 numbers to the actual block or square.

SEC. 5. The authorities of the village, town, or city incorporations in the county are recommended and urged to name the streets within their corporate limits, and to cause the houses thereon to be numbered; also, to make use of one of the following designations only for the roadways within such incorporation, viz.: Alley, Avenue, Boulevard, Court, Park, Place, Plaza, Promenade, Row, Square, Street, Terrace.

SEC. 6. Road measuring and numbering, as contemplated by this ordinance, are hereby defined and described as follows: All roads shall be measured along the surface line of the same, as near to the middle of the roadway as practicable, and laid off in imaginary blocks one tenth of a mile, or 528 feet frontage each, according to

the "Ten-block System of Numbering Country Houses." A line to indicate the division between these blocks, with the block number on either side of the same, shall be marked or painted upon the fence where practicable, and where it exists in a fair state of preservation, or upon any other permanent object on one or both sides of the road. The odd numbers shall be applied to the blocks on the left-hand side of the road, and the even numbers to the right-hand side. The block numbers shall be in figures not less than two inches nor more than two and one half inches in height where the fence board or other object will admit of this size, and so plainly painted as to be easily read from the centre of the road. The mile distances shall be distinguished in some suitable manner, as by a full circle, and the half-mile by a half circle or other suitable device.

SEC. 7. The initial point of measuring for roads leading from the county seat shall be the centre of the street immediately in front of the main entrance to the court-house at Martinez. Other roads shall be measured at the end nearest the county seat, and branch roads the same, or from the main road to which they are tributary.

SEC. 8. Note shall also be taken and a record kept of the block within which is located, and the number of feet in or within the block (i. e., the distance from the commencement of the block), of all bridges, large culverts, important permanent springs, drinking troughs, public monuments, summits, road crossings and intersections and objects of special prominence, and the correct block number be marked thereon, or near thereto, where practicable.

SEC. 9. Note shall also be made and a record be kept of the number of the block within which is located, and the number of feet in or within the block, of each and every house entrance or gateway, lane, or road leading from the highway to any residence upon the roads, or to which access is had by way of the road, with the name or names of the owner or occupant, when practicable to procure them; also, to the entrance to all school-houses, churches, and public buildings.

SEC. 10. The measurement of all roads which pass through or enter the corporate limits of cities or towns shall be continuous, regardless of such boundaries; but the block and country-house numbers may be omitted within such corporations.

SEC. 11. In the measurement of the roads of the county re-

quired by this ordinance a record shall be made and preserved of the general course of bearings by the compass of all roads at road crossings or intersections; also, the general course of all private or local roads at their point of departure from the main road; and it shall be the duty of the county surveyor to prepare and place on file, in the office of the clerk of the county, a complete road map of the county, with the names of all roads, and, whenever the same are measured, the block numbers at their commencement at all roads, crossings, and at all crossings and connections of all roads, and at their endings, together with the boundaries of the several road districts in the county.

SEC. 12. The measurement of the roads of the county may include the record of the accurate reading by barometer of the altitudes or elevations above the sea-level of the commencement and ending of all roads, all plains, valleys, the foot and summit of hills and the slopes of mountains, at suitable distances. The records of such altitudes, if taken, to be placed over the block number nearest the point of observation, or otherwise suitably posted, to show the range of important elevations traversed.

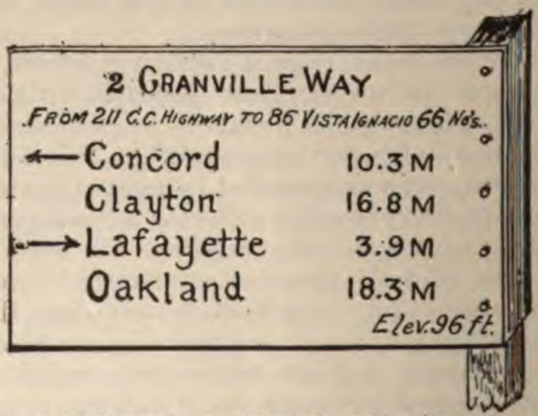
SEC. 13. Whenever one or more residents or owners, upon any road enumerated in section 29, or hereafter designated and described, as required by this ordinance, or other person, shall furnish the Board of Supervisors satisfactory evidence that the provisions of this ordinance, respecting road measuring and numbering, have been faithfully complied with upon any road touching the county seat, or upon any road connecting with any other road which has been previously measured and blocked off; and whenever such residents shall file with the county clerk the record required in sections 8, 9, and 11; and whenever such resident, residents, or other persons shall have affixed block numbers at the beginning and ending of such roads, and at each mile and half-mile division thereof, where practicable or oftener,—then, and in that case, it shall be the duty of the Board of Supervisors to erect upon such road, or roads, guide-boards, as hereinafter prescribed.

SEC. 14. Whenever any such road is so measured and block numbers designated thereon, thenceforth and thereafter the several requirements of this ordinance as to the maintenance of house numbers, the protection and preservation of guide-boards, etc.,

shall become applicable and in force along and upon such road, or roads, and the penalties herein prescribed shall be duly enforced.

SEC. 15. The guide-boards, when ordered upon any road, shall be erected and permanently maintained at the following-named points, and at such places as the Board of Supervisors may hereafter prescribe: At or near the commencement of all roads or branch roads, at all road crossings or intersections, at all ferry landings, at all railroad stations, and at all crossings of the county boundary. They shall be so placed on the principal roads as to face the traveller when moving from the county seat.

SEC. 16. Such guide-boards shall be of iron, not less than No. 16 in thickness, galvanized and painted. They shall be at right angles to fit the post, and with two arms or boards for the lettering. The outer edges shall be bent back from the face one half inch in width, the lower portion being cut away the width of the post, and the upper lip to rest on top of the post, to which the board must be securely atttached by a sufficient number of screws. The posts



NO. 1. ARRANGEMENT OF WORDING ON GUIDE BOARD.

shall be of sound redwood, 6×6 inches, and twelve feet long, to be set three feet in the ground, with cross-pieces nailed to the post, in light soils. The top and the portion below the ground to be in or painted with coal-tar, or some other wood preservative, the portion above the ground to be painted with two coats of good metallic or other suitable paint. The exposed surface of the boards

shall be 15×24 inches in size, each, except at the entrance to local roads, which may have but a single projecting arm 6×15 inches in size and affixed to a 4×4 inch post; in all other particulars to be of similar construction to the larger size; the wording and lettering to conform to the general plan indicated by the design accompanying this ordinance, and made a part thereof. All of the lettering upon the guide-boards, except the second line, which is in letters smaller than the others, and a section of eighteen inches of the two faces of the guide-post directly under the guide-board, shall be painted with luminous paint.

SEC. 17. Upon all guide-posts the following notice shall be conspicuously painted or stencilled:

A PENALTY FOR DEFACING OR POSTING.

SEC. 18. Whenever the provisions of section 13 have been complied with as to road or roads, and guide-boards have been erected, the supervisors shall also cause a printed notice to be served upon the occupants of every residence upon such road or roads outside the limits of incorporated towns, left at such residence, or, where the residence is distant a mile or more from the public or named roads, mailed to their address, accompanied by a copy of this ordinance or abstract thereof. Such notice shall also be delivered or mailed to one of the officers of each school district and church of which the building is located upon said measured road. These notices shall have a blank form, to be properly filled with the exact location and correct number of the entrance to the house, with instructions as to the house number to be posted and maintained.

SEC. 19. Every householder upon such measured road, residing outside the limits of incorporated towns, shall, within thirty days after the service of the notice required in section 18, post, and thereafter permanently maintain in legible condition, upon the road or at the entrance or right of way from the road, the correct house number of his residence as given in said notice. It shall be placed in such a conspicuous position as to be easily seen and read from the centre or opposite side of the road. The figures shall be well proportioned, and of a size not less than three inches in height, nor more than four inches, except in town or village settlements, where the numbers may be one inch less in height, and may be maintained upon the doorway or at the gate. The numbers must

be neatly made, and in the style and manner that a professional sign-writer would use.

SEC. 20. Any owner or occupant of any dwelling in the county which is reached by a private road or right of way is hereby permitted to post and maintain his house number upon the public highway at the entrance to such private road or right of way, or upon such private road or right of way, and he or she may place therewith his or her own name and business, provided such sign is made in a neat and tasteful manner, and conforms to the provisions of this ordinance.

SEC. 21. Whenever the occupant of any dwelling upon a measured and numbered road shall fail for the term of thirty days to maintain the proper house number at the entrance thereto, and having been notified by the road officer to comply with the law shall fail to do so, he shall be deemed guilty of a misdemeanor.

SEC. 22. Whenever any house upon a measured and numbered road now vacant shall be occupied, or any new dwelling-house shall be erected upon such road, it shall be the duty of the occupant within thirty days to properly post and thereafter permanently maintain, at the entrance thereto, the correct house number of the same as provided in this ordinance, and such residence shall thereafter come under the provisions of this ordinance the same as dwelling now occupied.

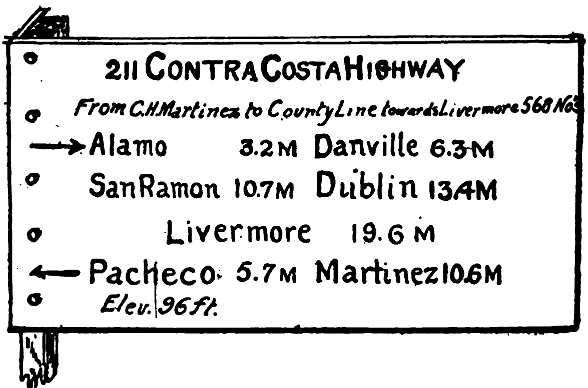
SEC. 23. There shall be prepared for county use a book of records for the roads of the county, in which shall appear, arranged in proper order, under the name of each road, an index of all ordinances or other official action relating to that road, making such road record an official history of all the roads of the county.

SEC. 24. A copy of all the field notes of the survey measurements, elevations, and other records, with the block and house numbers as provided for, shall be carefully preserved in the office of the county clerk, and open to the inspection of citizens as are other county records.

SEC. 25. The execution of the work required by this ordinance shall be subject to the inspection and be made to conform to the requirements of a road committee to serve without pay, and to consist of three members, one to be appointed by the Board of Supervisors, one to be named by the road-naming committee who have prepared this plan, and the third to be chosen by the two thus

appointed, and all to be confirmed by the Board of Supervisors; and any work of measurement, erecting guide-boards, or affixing numbers, shall not be held to be complete until approved by a majority of this committee.

SEC. 26. It shall be the duty of the road officials to thoroughly inspect the roads within their respective districts and to make reports to the Board of Supervisors at least as often as at the close of each six months of their terms of office, as to the condition of such roads, and any failure to comply with the provision of this ordinance. They shall also see that guide-boards are preserved in a legible condition and house numbers properly maintained, notifying residents of any neglect in this respect. It shall be their duty to report any person charged with violating the provisions of this ordi-



NO. 2. GUIDE BOARD AT RIGHT ANGLES TO NO. 1.

nance, and to enter complaint against them in such case; they shall also have full authority to arrest any person or persons found defacing or removing block or house numbers, or mutilating any guide-board, or posting any notice upon the post or boards, or in any way violating the provisions of this ordinance.

SEC. 27. If any person or persons shall mutilate, deface, destroy, or remove any guide-board or guide-post, any block or house number, any name, sign, or advertisement which may be lawfully posted at or upon the entrance to the residence or dwelling of any person to whom such notice belongs, whether such entrance be public or private or through right of way, or shall mar, deface, or injure, by shooting, stoning, or otherwise, any guide post or board, or shall

fasten, or paint, or stencil any notice or advertisement to such posts or boards, save such as are required by this ordinance, the person or persons so offending shall be deemed guilty of misdemeanor, punishable, upon due conviction, by a fine of $50, one half of which shall go to the informer, or by imprisonment, or both.

SEC. 28. The roads of the county, as enumerated in section 29, are listed according to the following rule: Commence on the east side of a line extending due north from the county seat and work around in a circle to the east, southwest, and back again to the north, always facing outward and working from the county seat outward, and always from the left to the right. List first those roads touching the county seat; next the first left-hand branch roads, and any left-hand branches of these. Continue with the right-hand branches, follow with the remaining trunk roads and their branches, left-hand branches first, right-hand branches next; omitting nothing on the left until the entire circuit has been made and the roads of the county are all listed. Under this rule the roads leading from Martinez, five of them are first listed; then the first of the five which have branches, No. 2, and then continued in the order explained above.

SEC. 29. The following are the names of several public highways and private or local roads of the county, respectively hereby authorized and established. [List of 130 roads, among which are:

Alpha Way, from Martinez to Bull's Head; Contra Costa Highway, from Martinez to County line *via* Pacheco, Walnut Creek, and San Ramon Valley; Alhambra Way, from Martinez to Pinole; Granville Way, from Contra Costa Highway, near Walnut Creek, to Vista Ignacio, Franklin Road; Teal Local; Tule Road, Pecheco Exit, Vine Hill Way.; Locust Way, Plover Connex; Willow Pass Road; Flunaveg (River Road), Black Diamond Way; Empire Road; Paso Corto; Camino Diablo, Carbon Way; Arbor Connex; Lone Tree Road, Almond Way; Summer Road, Dry Creek Local; Zigzag Way, Sunol Local; Concord Lateral; Pomona Road; Ferndale Local; Golden Gate Way; Vaca Crescent; Verdel Circuit; Acorn Local, Highland Drive; and Forest Road.]

SEC. 30. This ordinance shall take effect and be in force on the 16th day after its passage.

Passed March 8, 1892.

INDEX.

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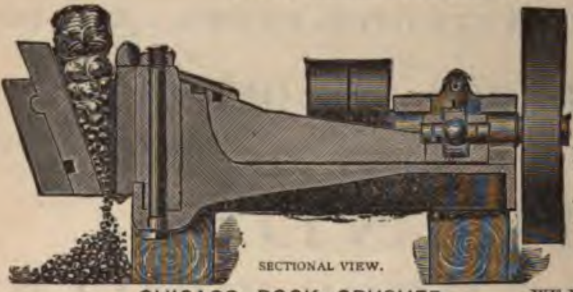

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